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CIVIL EFFECTS EXERCISE

THE RADIOLOGICAL ASSESSMENT AND RECOVERY OF CONTAMINATED AREAS

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CIVIL EFFECTS TEST OPERATIONS
U.S. ATOMIC ENERGY COMMISSION

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THE RADIOLOGICAL ASSESSMENT AND RECOVERY OF CONTAMINATED AREAS

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ABSTRACT

The Civil Effects Test Operation Exercise CEX-57.1 following Operation Pumbbob was carried out to obtain information on decontamination procedures that could be used as radiological countermeasures. The test was conducted on D + 1 and D + 2 days after shot Coulomb C. Data were obtained on reclamation of land areas by scraping with a motorgrader, on fire-hosing and scrubbing a concrete-slab roof, and on fire-hosing a composition roof. In addition, some shielding data were obtained for a small building with 6-in.-thick concrete walls and roof.

The conceptual nature of a radiological defense system and the role of decontamination or reclamation in such a system are discussed. Most of the report deals with methods for reducing the observed data to interpretive form because the data were taken within a large contaminated area.

The decontamination effectiveness in terms of the fraction of contamination remaining was computed to be: (1) 0.2 to 0.3 for scraping with a motorgrader (1 pass with $1\frac{1}{2}$-in. cut); (2) 0.3 to 0.4 for fire-hosing a concrete roof (1 pass, 50-psi nozzle pressure); and (3) 0.3 to 0.4 for fire-hosing a composition shingle roof. No significant additional amount of fallout was removed from the concrete roof when it was scrubbed after fire-hosing. These results are high compared to other data owing to the low levels of contamination and error in the measurements and data analysis methods.

It is concluded that low levels of contamination at the Nevada Test Site could be utilized to advantage to obtain data on gamma-radiation properties, such as the effects of materials and source geometries on the attenuation of fission-product gamma rays. However, higher levels of fallout, in terms of the fallout particle mass, are required to obtain useful information and training on decontamination techniques; therefore, the use of low levels of contamination to conduct studies in this area is not recommended.

ACKNOWLEDGMENTS

This report summarizes the results of a special exercise conducted during December 1957. Several laboratories and many individuals cooperated in this effort, and it is not feasible to mention each person by name. The U. S. Naval Radiological Defense Laboratory provided scientific direction and prepared the detailed technical report and support of the field work. The Division of Biology and Medicine, USAEC, Washington; the Health and Safety Laboratory, USAEC, New York Operations Office; and Brookhaven National Laboratory provided personnel to assist in the conduct of the experiment as did Reynolds Electrical and Engineering Company, Inc., the support contractor for the Nevada Test Site.

CONTENTS

ILLUSTRATIONS

ILLUSTRATIONS (Continued)

CHAPTER 5 TREATMENT OF THE DATA

TABLES

CHAPTER 4 RESULTS

TABLES (Continued)

CHAPTER 5 TREATMENT OF THE DATA

CHAPTER 6 SUMMARY AND CONCLUSIONS

Chapter 1

OBJECTIVES AND SCOPE

The objectives of Civil Effects Exercise 57.1 were to utilize the existing facilities at the Nevada Test Site (NTS) to:

1. Determine the feasibility of obtaining information on radiological countermeasures through the use of decontamination techniques on residual radioactive material (fission products) remaining at certain on-site locations.
2. Determine the feasibility of using areas of low-level contamination for purposes of orientation and training.
3. Obtain data on the effectiveness of proposed decontamination procedures and techniques.

The Exercise, as originally set up, was to utilize an area of the test site that had been contaminated by a shot from Operation Plumbbob. Previous to the Exercise itself, no particular shot or location on the test site was designated to be used in the Exercise. The first step was to monitor several likely locations and select one or more of them for the Exercise problem. It was generally known that radiation levels appreciably above background existed in various locations on the test site from the shots detonated during Operation Plumbbob. The radiation measurements were planned to be taken with AN/PDR/T1B type instruments, and the decontamination methods were to be selected on the basis of the area(s) chosen for the Exercise. The equipment to be used in the decontamination, also to be selected on the basis of the area(s) chosen, included motorgraders, fire hoses, bulldozers, motorized scrapers, scrub brushes, and/or other equipment and was furnished by the Test Organization.

On Dec. 9, 1957, one day before the test was to be conducted, a low-yield near-surface detonation contaminated an area containing several structures. Since the freshly contaminated areas were of higher levels than existed on other structures on the site, the original plan for the field operations part of the Exercise was altered to take advantage of the new radiological situation. Although the radiation levels were only between 30 and 40 mr/hr on the day the Exercise was actually initiated, the fact that the condition of contamination was new and in an area not previously contaminated to any significant amount during the Operation indicated that the area was better suited to the objectives of the test than any other then existing.

Therefore the original field conditions under which the objectives of the Exercise were to be fulfilled were not utilized owing to the availability of structures and areas contaminated by the Coulomb C shot on Dec. 9, 1957, one day before the Exercise was to be conducted. Although the event of Coulomb C did not change the objectives of the Exercise, it radically altered the original intent of the objectives.

The scope of this report includes mainly a discussion of the reclamation procedures and their performance in the fallout area where rather low contamination levels from shot Coulomb C existed. In addition to describing the experiment and presenting data, this report discusses background information and analytical techniques necessary for the reduction and interpretation of decontamination data. The details are presented to indicate as clearly as possible the difficulties involved and the effort required in planning, executing, and interpreting decontamination experiments conducted at field tests. Such information also is often helpful in the design of future experiments.

The intent of the conclusions of the report is to evaluate the objectives of the Exercise in terms of the utility of the information gained in the Exercise as it was carried out as well as for conditions that might have prevailed if Coulomb C had not occurred.

Chapter 2

BACKGROUND

Because of an increasing concern over national security by individuals and various governmental agencies along with an increased knowledge of the potential hazards due to fallout from near-surface (or other) nuclear detonations, more attention has been focused on obtaining information on radiological countermeasure operations and procedures.

Work in radiological decontamination has been conducted by agencies of the Army, Air Force, AEC, and Navy. However, the only continuous effort in the field since 1950 has been conducted for these various agencies by the U. S. Naval Radiological Defense Laboratory, mainly for Navy. The work to date has resulted, at least in the conceptual stage, of a radiological countermeasure system that has sufficient technical verification for potential success, if implemented, in saving many lives if a nuclear war were to occur. A brief summary of the nature of this system and the purpose of its various parts is given below to make self-evident the role of the described Exercise in obtaining data to improve the information required and how it can be utilized in implementing and improving the operation of the system.

The general purpose of radiological countermeasure actions is to reduce, or eliminate, the expected gain to an enemy in a nuclear attack as a result of radiological effects. The specific objective of a given countermeasure system for an industrial establishment or fixed military installation, for example, would be to reduce to an acceptable amount the delay time in getting the plant back into operation after attack.

The chief radiological effect of interest from nuclear weapon detonations is fallout. In contrast to the blast and thermal effects, which are of very short duration, the radiological effects from fallout are of long duration. Thus radiological countermeasures, to be effective, must be planned as a systematic series of actions taking place over a period of time. The general types of appropriate countermeasure actions needed can be deduced from the variation of the radiological effect with time and the magnitude or the intensity of the effect. There are three unique time phases of countermeasure actions, and these phases are associated with the level, or severity, of the radiological hazard.

A "major involvement" is defined as a radiological involvement in which no unshielded operations can be carried out without incurring casualties. Major involvements will occur within minutes to several hours after detonation; because the radiological hazard is most severe at these early times after detonation, the countermeasures for these involvements are called "emergency-phase actions." The central countermeasure in this phase is shelter, and the phase objective is survival.

After fallout has ceased and the radiation intensity decreases (owing to decay of the radionuclides) to a given level (depending on the dosage allowed), limited unshielded operations will be possible. The countermeasure action of the limited-exposure period is to decontaminate and reclaim vital areas so that unshielded operations can be resumed. This phase is termed the "operational recovery phase." The central countermeasure in this phase is reclamation, and the phase objective is to regain the operation of the plant or installation. (An "intermediate involvement" is defined as a radiological involvement in which the severity of the radiological effect never rises above the level for limited shielded operations; thus, an intermediate involvement has no emergency phase, only operational and final recovery phases.)

After the radiation decays or is decreased by reclamation to a level sufficiently low that no shielding is required, the major involvement condition goes into the "final recovery phase." In this phase the chief radiological hazard is the ingestion of long-lived radionuclides. The objective of this phase is the control of radioactivity and the elimination of radioactivity from biological systems. No central countermeasure for this phase has yet been found because the exact nature and level of the hazards have not yet been determined. (A "minor radiological involvement" is one in which the radiation level never reaches the intensity requiring even limited shielded operations; thus this involvement does not have an emergency or an operational recovery phase.)

An optimal selection of countermeasure actions leading to a minimum (or prestated) radiation dose over all phases constitutes a countermeasure system. The manpower, equipment, and supplies required for the individual countermeasures are called "countermeasure components." The information needed to make an optimal selection of countermeasure actions includes (1) knowledge of the radiological effects of weapons with time, space, and magnitude for all yields of weapons, (2) knowledge of the biological effect over the complete range of hazard levels so that the consequences can be used to recognize the appropriate phase of countermeasure actions, and (3) knowledge of the effectiveness (including cost) of countermeasure components. For a countermeasure system in which the least expenditure of allowable dosage is budgeted in attaining the over-all objective of the system, the performances of the available components in one phase will influence the required performance of those in another (and even the length of the phase itself). For example, a high-performance (negligible dose) shelter combined with a low-performance reclamation procedure might cost the same total dose accrual as a less effective shelter combined with a highly effective reclamation procedure.

Chapter 3

EXPERIMENTAL PROCEDURES AND MEASUREMENTS

3.1 RECLAMATION PROCEDURE

The locations of the two contaminated structures that were selected for use in the Exercise with respect to Ground Zero of the contaminating event are shown in Fig. 3.1. Building A (Station 31.1E2) had a concrete-slab roof; building B (Station 31.1C2) had a composition-shingle gabled roof.

The operational plan for reclaiming the two structures and an area surrounding them was as follows (the details for each step are given in the following sections):

1. An area surrounding each structure was staked out, and monitoring stations were set up on the roof of each structure and inside structure A.
2. The areas and structures were monitored.
3. The area around structure A was scraped.
4. The roof of structure B was decontaminated by washing down with a fire hose.
5. The areas and buildings were monitored.
6. The roof of building A was decontaminated by washing down with a fire hose.
7. The roof of structure A was monitored.
8. The area around structure B was scraped.
9. The roof of structure A was scrubbed with detergent and then with water.
10. The roof of structure A, the roof of structure B, and the area around structure B were monitored.

3.2 MONITORING

Decay measurements were taken at a station located between the two buildings at several times during the experiment.

The monitoring stations were set up in the same manner for both buildings. The station array used is shown in Fig. 3.2.

The locations and numbers for the stations on the roofs are given in Fig. 3.3; the positions designated by a number in parentheses indicate a single extra survey. The station locations inside building A are shown in Fig. 3.4.

Two readings were taken at each station; one at surface level and one at 3 ft (waist level) above the surface. All measurements were made with AN/PDR-39(T1B) radiac instruments. The radiacs were calibrated at the Rad-Safe building in the CP-2 area. In the treatment of the data, the use of the paired readings at the two heights is illustrated.

3.3 SCRAPING PROCEDURE

The scraping procedure was carried out with a single motorgrader. The surface of the soil around building A was fairly smooth and contained few, if any, large rocks. Since only a motorgrader was to be used without a scraper to pick up the windrows, the depth of cut was set to about $1\frac{1}{2}$ in. (i.e., as shallow as possible). This permitted the motorgrader to push the windrows out to about 150 ft on each side of building A (170 ft from the center of the building). For scraping the area was divided into six sections; the first cut was made on a line passing one side of the building pushing the top soil outwards. The motorgrader backed across the cleared area between each cut. After several passes when the windrow became large, the section was halved at right angles and again pushed to either side of the center cut. Only a small section remained when these windrows became large. The short windrows were pushed out using the motorgrader as a bulldozer or by taking a diagonal cut starting at the outer end of the windrow. A few hot spots remained where the blade "missed" owing to depressions in the soil surface; time did not permit taking a second pass over the area. The final area cleared around building A was about 340 by 340 ft. The operation was started the afternoon of D + 1 and finished the morning of D + 2.

Around building B (step 8), the motorgrader scraping was accomplished by circling the building and pushing the soil outward. At the end of D + 2 operations, a swath 60 ft wide (75 ft from the building center) was scraped; this was about as far as the motorgrader could be used even with the shallow cut without removing the windrows with another piece of equipment (motorized scraper). The surface of the soil around building B was rougher than that around building A.

The structures and the cleared area around building A (at the right) are shown in Fig. 3.5; another view of the cleared area and the size of the windrows around the edge of the areas is shown in Fig. 3.6. The circular cleared area about building B is shown in Fig. 3.7.

3.4 DECONTAMINATION OF ROOFS

The roof of building B was washed down using a water-tank truck with pump and a fire-hose nozzle. The pressure was adjusted by varying the speed of the pump to approximately 50 psi nozzle pressure. At the levels of radiation encountered (20 to 30 mr/hr at D + 1), there were no fallout particles visible. This made it somewhat difficult to assure a good coverage with the fire hose. Washing was accomplished by going horizontally along the roof, starting at the peak, and trying to put the full force of the spray on a swath 2 to 3 shingles wide per pass. On the concrete-slab roof (building A) some clean earth from the cleared area was sprinkled over the roof to aid the operator. In the latter case, the roof was divided into strips about 5 or 6 ft wide across the width of the slab, and the fire-hosing was carried out by swinging the hose from one side to the other as the operators moved slowly along the length of the strip. After the first strip was cleaned, the nozzle operator took station on the edge of the clean strip so that in swinging the nozzle on the adjacent contaminated area the spray would not scatter fallout particles back onto the cleaned areas.

The concrete-slab roof was scrubbed with detergent after a single pass with the fire hose (allowing time in between for monitoring). The detergent was mixed with water before application; the solution was poured over sections of the roof and in the scrubbing process was spread about further. After one section was scrubbed, solution was poured on an adjacent section until the whole roof had been treated. The whole area was then flushed with the fire hose; the surface did not dry before it was flushed.

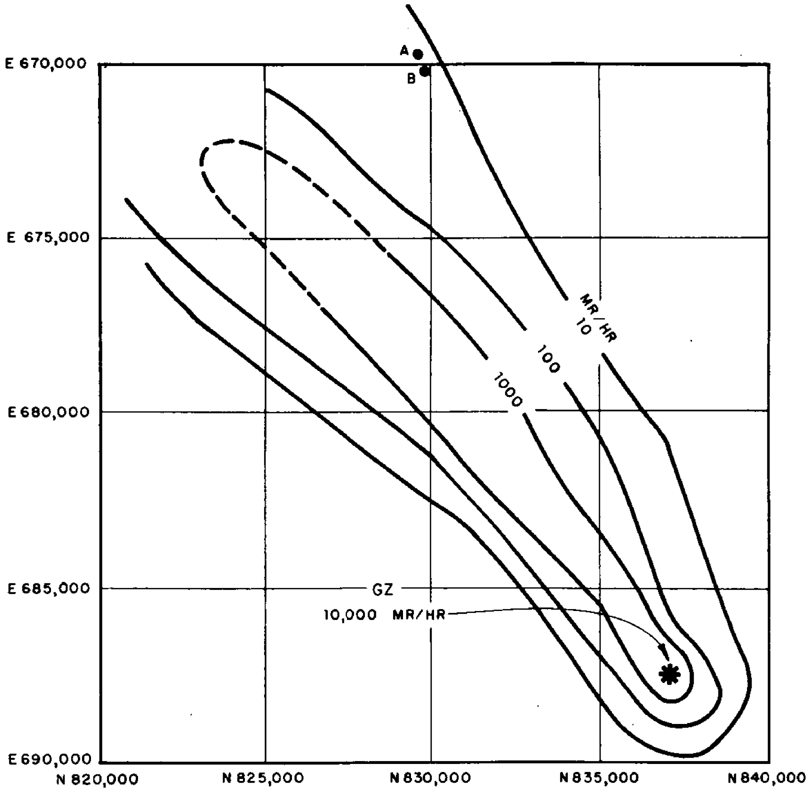

Fig. 3.1—Location of buildings in fallout area from shot Coulomb C.

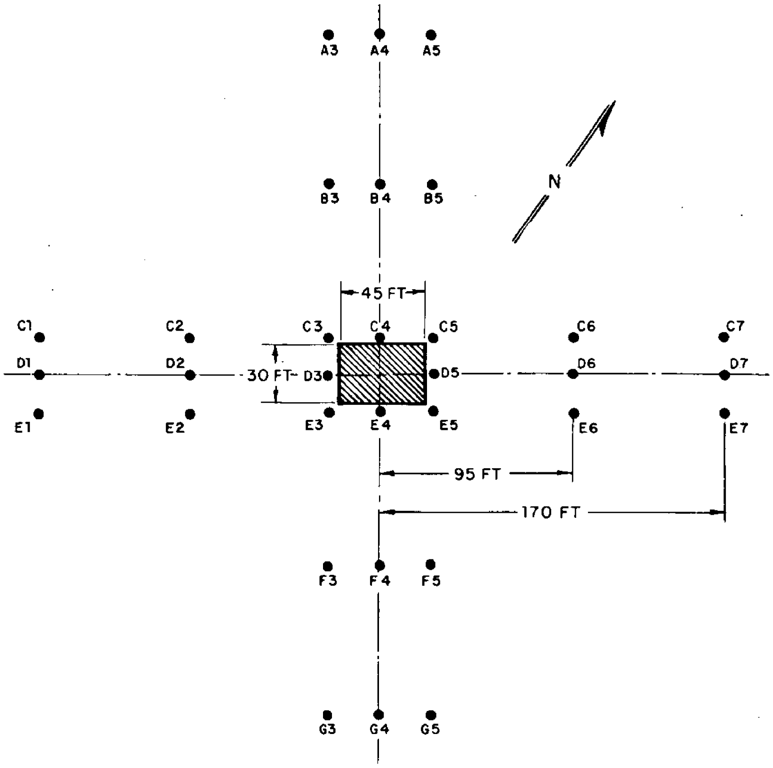

Fig. 3.2—Monitoring-station array around buildings A and B.

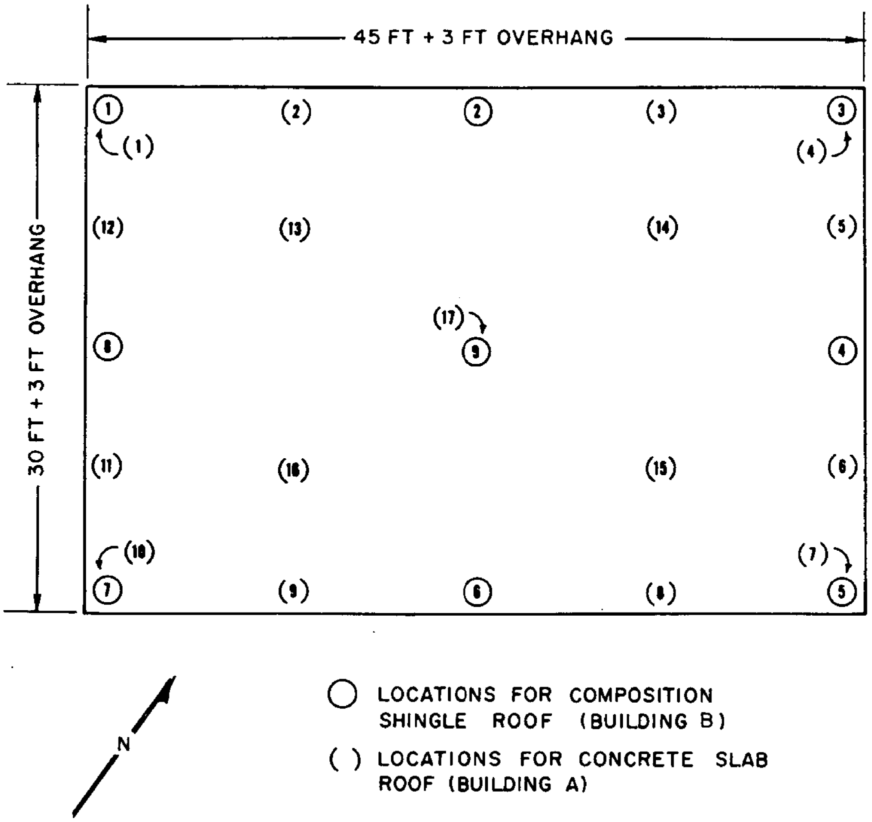

Fig. 3.3—Monitoring-station array on building roofs.

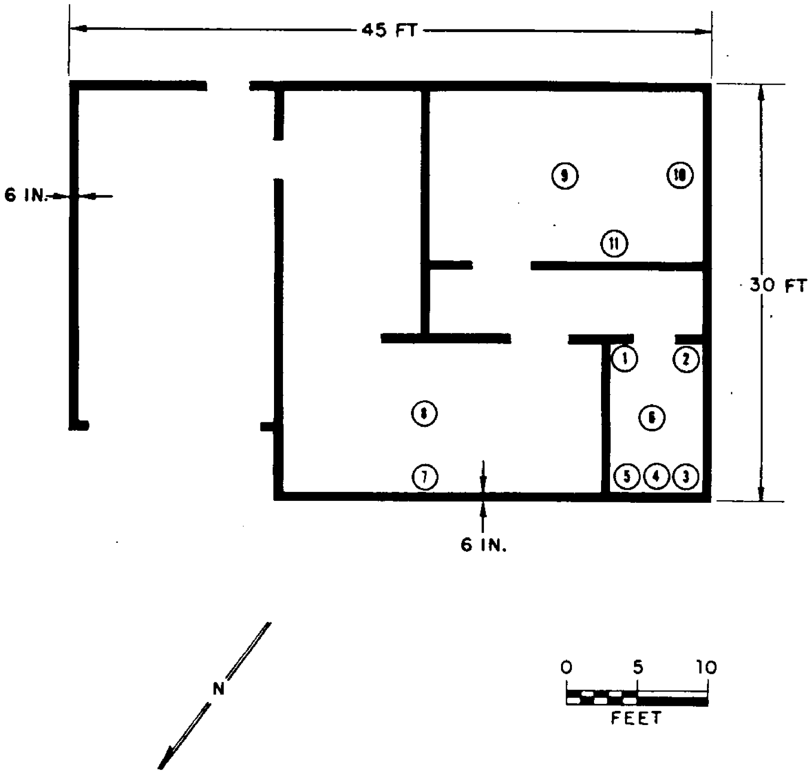

Fig. 3.4—Monitoring-station locations in building A.

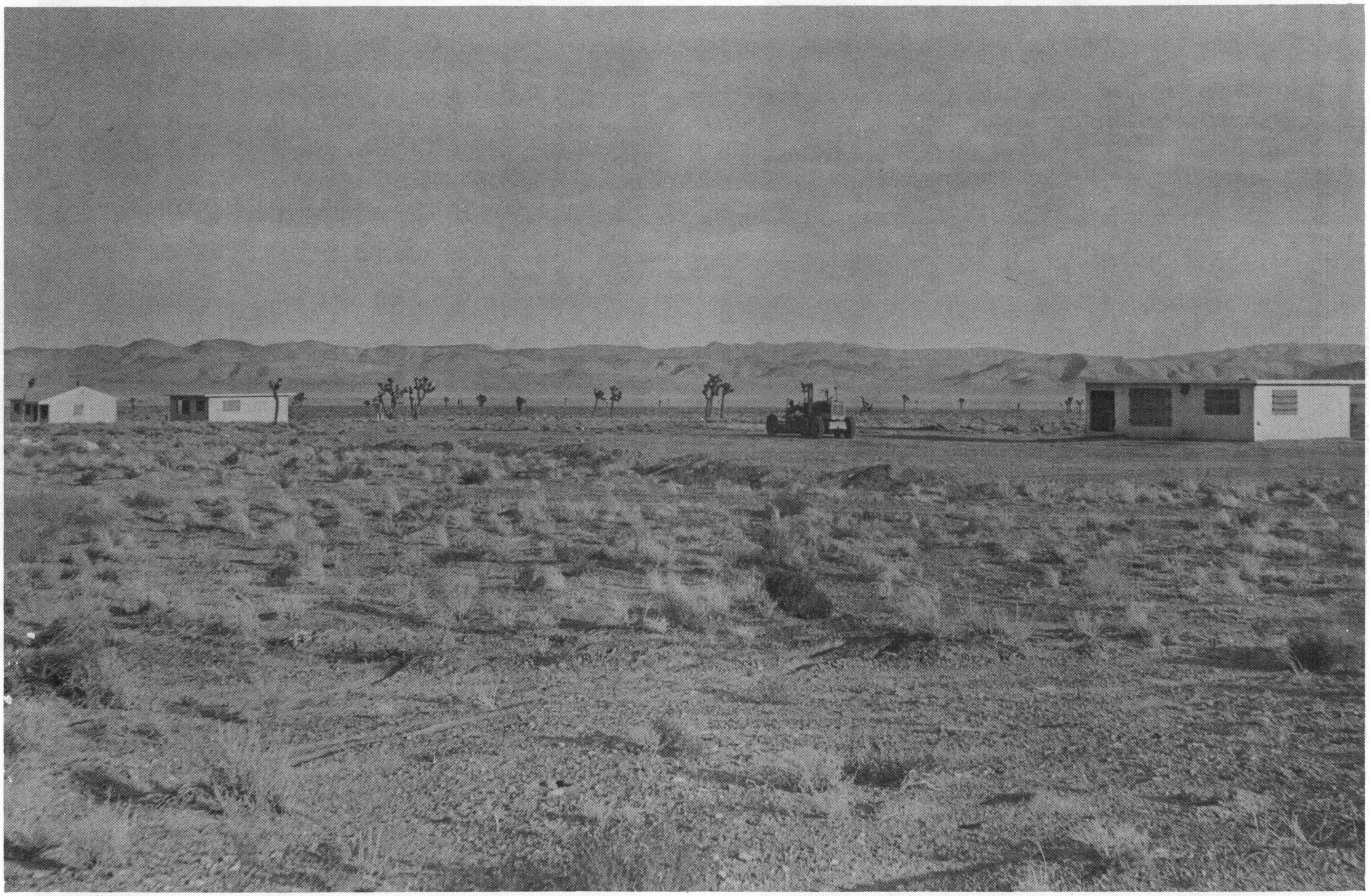

Fig. 3.5—Photograph of building A (right), building B (left), and cleared area around building A.

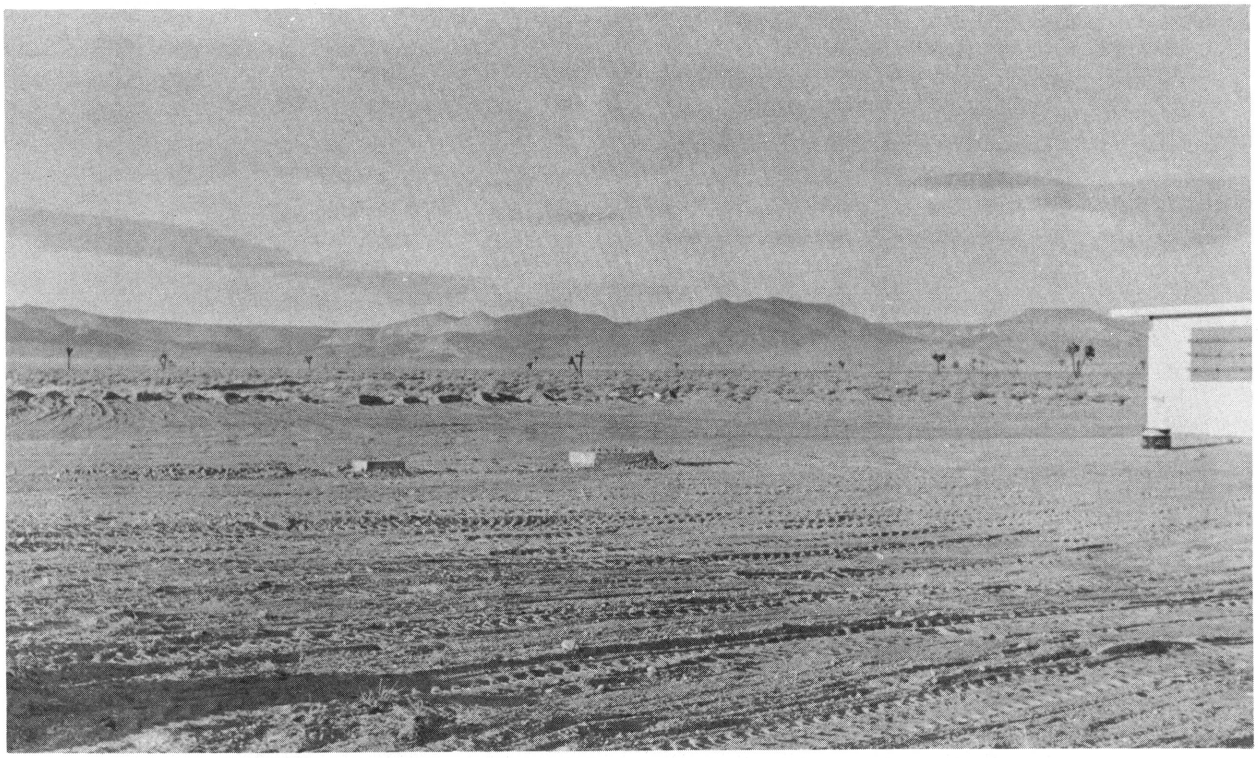

Fig. 3.6—Cleared area around building A.

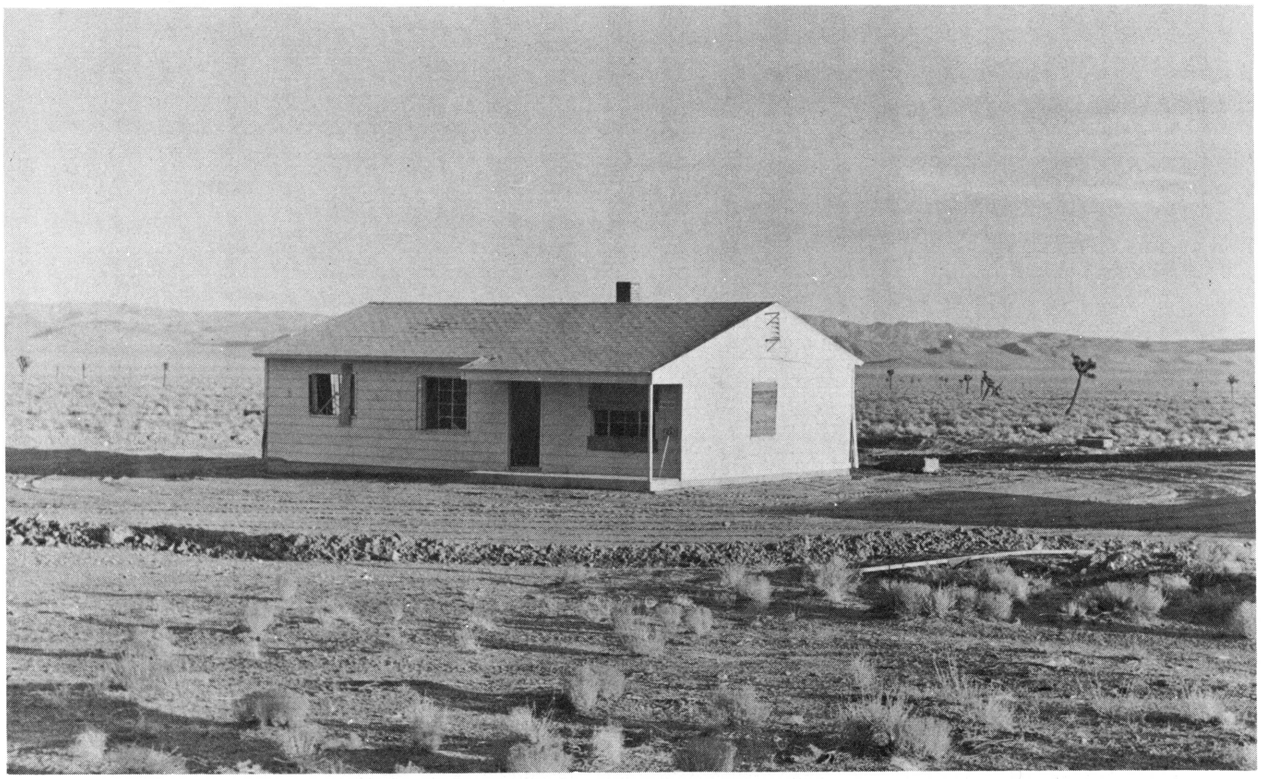

Fig. 3.7—Cleared area around building B.

Chapter 4

RESULTS

4.1 DESCRIPTION OF FALLOUT DECONTAMINATION PROCESSES

Any discussion of the interactions between fallout and material surfaces requires a clear statement of what fallout is. Surface reactions are extremely sensitive to the composition of the surface and to the nature of the substance making contact. Surface reactions of ions, colloids, and larger particles are all entirely different; in fact, surface reactions of ions of the same charge but of different size are different. Because of these differences, a precise description of what fallout is must be made to establish the basic concepts of decontamination.

As described in the previous section, the more or less spherical particles carrying the radioactive elements arise from molten silica. These particles are insoluble in water and most acidic solutions, and the radioactivity in them is not released to any great extent in such media. Long-range fallout and fallout particles formed from a water-soluble matrix are entirely different substances. Aqueous media will leach or dissolve fission products from the water-soluble particles and particles where the activity is only adsorbed on the surface.

The interactions of interest for fallout from a land detonation are those that take place between silica particles and surfaces; the sizes of interest are from 75 μ and larger since these carry with them the major fraction of the radioactivity. A decontamination process that removes these particles from a surface also removes the radionuclides fused inside the particles.

In a practical sense, the nature and strength of the forces holding particles to surfaces are not required to describe, in a general way, an observed decontamination result. Approximate relations between the mass of fallout deposited per unit area of surface and the amount remaining after application of a decontamination method such as fire-hosing have been developed.[1] Most of the common decontamination methods tend to reduce the initial deposit to a given amount, providing the initial deposit is heavy enough to give at least a unit layer of particles on the surface; thus, if the amount remaining is a constant, R_M, for a given surface-decontamination method combination, the fraction remaining is inversely proportional to the initial amount, or

$$F = R_M/y \tag{4.1}$$

where F is the fraction remaining and y is the amount deposited in mass per unit area. In addition to the decontamination method and nature of the surface, the value of R_M presumably depends on the particle-size distribution of the mass deposited; but, where the general size distributions are roughly the same, this effect would be small. For deposits of less than a unit layer of particles, R_M is multiplied by the fraction of the unit area covered with particles; when this is done,[1] Eq. 4.1 becomes

$$F = \frac{R_M\,(1-e^{-ky})}{y} \tag{4.2}$$

where e^{-ky} is the probability of a falling particle landing on the surface rather than on previously deposited particles at the deposit level y, and k is a constant that depends on the roughness of the surface (and also the size distribution of the particles). The limiting value of F at low values of y is $R_M k$.

For decontamination data obtained from radiation-intensity data, evaluation of Eq. 4.2 requires a relation between mass of fallout and radiation intensity, i.e., the average specific activity and the ionization from the emitted photons that apply to the geometry of the measurement. An approximate relation[2] is

$$M_r^{\lambda}(t) = \frac{KW^n}{(A_0/A_\lambda) q\, b[i_{FP}(t) + i_I(t)]} \tag{4.3}$$

where $M_r^{\lambda}(t)$ = the mass contour ratio given as the ratio of mass per unit area to roentgens per hour

W = the total yield

(A_0/A_λ) = the correction factor from the scaled depth, $\lambda(=h/W^{1/3})$, to a surface detonation

q = the terrain factor

b = the ratio of fission to total yield

$i_{FP}(t)$ = the theoretical air ionization for a given number of fission products for unit area

$i_I(t)$ = the theoretical air ionization from the corresponding relative number of induced activities per unit area

K = a constant that relates yield to number of fissions, fissions to number of fission products and, via their photon emission, to air ionization intensity, and, lastly, yield to the mass of soil that becomes associated with the radioactive products formed in the detonation

h = depth of burst in feet for W in pounds of TNT equivalent

For the ionization rate I(t) at time t after detonation, Eq. 4.2 is then

$$F = \frac{R_M\,[i - e^{-kM_r(t)I(t)}]}{M_r(t)\, I(t)} \tag{4.4}$$

Equations 4.3 and 4.4 suggest several things in relation to the experiment described in this report. First, the amount of information required to interpret the data relative to data obtained from previous experiments is extensive (yield, height of burst, radioactive composition, terrain factors, etc). Most important, of course, is the variation of F with initial intensity I(t). Equation 4.4 predicts that F increases as I decreases; thus an apparent low effectiveness in decontamination at low values of I(t) could be erroneously interpreted, especially by trainees, in an exercise of this kind. Also, an error in the determination of the equation constants from empirical data at low levels would be more serious than those determined from data obtained at levels comparable to a major radiological involvement; it would be better to use Eq. 4.4 to extrapolate data from high levels to low ones rather than the reverse. Since Eq. 4.4 is not an exact representation for all parameters included and since most data contain errors, the equation should not be used to estimate F values for contamination conditions that are extremely different from those used to evaluate the equation constants.

4.2 SUMMARY OF MEASURED DATA

The summary of measurements made before and after grading and fire-hosing is given in Tables 4.1 to 4.9. The measurements of the field decay are shown in Table 4.10. The time required and the coverage rate for each of the reclamation procedures are shown in Table 4.11. In order to make direct comparisons of all monitor readings, they were decay corrected to D + 1; the corrected readings are summarized in Tables 4.12 to 4.18. A description of the methods used to obtain the decay corrections from the data is given in Chap. 5. [In all tables the position marked "X" is the center of the building.]

The decay-corrected data for the initial surveys indicate a rather uniform deposit of fallout around the two buildings and, with some exceptions, on the two building roofs. The data for the two scraping operations reflect the general reduction in levels achieved, especially the surface readings. The surface measurements also indicate that occasional hot spots were left. These were due either to spillage that the operator failed to notice and remove or to low spots or indentations in the surface that were deeper than the $1\frac{1}{2}$-in. cut. These occur more often in the data for building B than for building A; it may be noted, however, that the areas around stations in the rows A and G and columns 1 and 7 were not scraped with the grader.

The measurements for the decontamination procedures on the roofs do not indicate a very high degree of effectiveness for those procedures; however, the readings contain contributions from sources other than the roof and therefore cannot be directly evaluated. In fact, none of the observed data, except the shielding data, can be evaluated without proper detailed treatment and analysis. The detailed treatment of the data and the results therefrom are given in Chap. 5.

REFERENCES

1. C. F. Miller, Estimated Effectiveness of Common Radiological Decontamination Methods for Paved Areas and Building Surfaces, March 1957.
2. C. F. Miller, Theory of Decontamination. Part I, Report USNRDL-460, July 1958.

TABLE 4.1—MEASUREMENTS OF AREA ABOUT BUILDING A BEFORE SCRAPING
(Time: 1230-1330, 12/10/57)

	Row						
Station	1	2	3	4	5	6	7
				Surface readings, mr/hr			
A	30	34	35	32	31	26	32
B	34	34	30	28	29	28	27
C	36	36	33		26	29	28
D				X			
E	34	33	28	28	29	29	29
F	34	32	30	30	29	28	34
G	38	34	35	30	29	30	36
				3-ft readings, mr/hr			
A	26	30	30	28	27	24	25
B	29	28	26	15	24	23	25
C	30	33	29		22	24	25
D				X			
E	30	27	26	26	24	25	26
F	30	27	27	26	26	25	29
G	30	29	27	29	27	29	29

TABLE 4.2—MEASUREMENTS OF AREA ABOUT BUILDING A BEFORE SCRAPING
(Time: 1300, 12/10/57)

	Row						
Station	1	2	3	4	5	6	7
				Surface readings, mr/hr			
A			30	29	29		
B			33	32	31		
C	28	30	22	24	15	25	25
D	30	33	24	X	28	25	24
E	30	28	46	39	18	25	27
F			27	27	28		
G			27	26	28		
				3-ft readings, mr/hr			
A			28	27	27		
B			29	27	27		
C	22	12?	20	16	12	24	14?
D	16?	26	30	X	13	24	24
E	24	24	32	26	19	13?	24
F			23	26	26		
G			25	25	25		

TABLE 4.3—MEASUREMENTS OF AREA ABOUT BUILDING A AFTER SCRAPING
(Time: 1110, 12/11/57)

	Row						
Station	1	2	3	4	5	6	7
			Surface readings, mr/hr				
A			10	6	2		
B			1	2	1		
C	6	2	4	2	1	2	5
D	4	6	3	X	4	2	4
E	12	2	4	3	2	2	5
F			2	3	15		
			3-ft readings, mr/hr				
A			8	7	4		
B			2	3	2		
C	5	4	2	3	4	2	5
D	5	4	3	X	2	2	5
E	9	3	4	4	3	3	6
F			3	3	7		

TABLE 4.4—MEASUREMENTS OF AREA ABOUT BUILDING B BEFORE SCRAPING
(Time: 1400, 12/10/57)

	Row						
Station	1	2	3	4	5	6	7
			Surface readings, mr/hr				
A			28	25	27		
B			26	26	28		
C	29	28	33	34	30	30	42
D	29	32	29	X	31	33	37
E	28	31	31	22	26	37	40
F			36	39	44		
G			44	42	42		
			3-ft readings, mr/hr				
A			25	23	25		
B			25	23	24		
C	25	25	22	20	22	29	36
D	26	28	22	X	19	30	34
E	26	29	26	22	21	32	38
F			33	33	34		
G			39	37	36		

TABLE 4.5—MEASUREMENTS OF AREA ABOUT BUILDING B BEFORE SCRAPING
(Time: 1015, 12/11/57)

	Row						
Station	1	2	3	4	5	6	7
Surface readings, mr/hr							
A				12			
B				12			
C							
D	14	15		X		18	19
E							
F				20			
G				22			
3-ft readings, mr/hr							
A				10			
B				11			
C							
D	11	12		X		16	17
E							
F				16			
G				17			

TABLE 4.6—MEASUREMENTS OF AREA ABOUT BUILDING B AFTER SCRAPING
(Time: 1310, 12/11/57)

	Row						
Station	1	2	3	4	5	6	7
Surface readings, mr/hr							
A			12	12	12		
B			3	16	8		
C	12	9	4	15	6	5	18
D	14	2	5	X	2	12	18
E	14	6	5	2	5	5	17
F			3	7	5		
G			20	20	18		
3-ft readings, mr/hr							
A			11	10	10		
B			4	6	6		
C	11	5	4	5	5	6	16
D	11	4	4	X	3	8	16
E	11	6	5	4	6	8	17
F			5	4	9		
G			18	17	17		

TABLE 4.7—MEASUREMENTS ON CONCRETE-SLAB ROOF OF BUILDING A

Station	Before scraping (1230-1330, 12/10/57)	After scraping (1130, 12/11/57)	After fire-hosing (1300, 12/11/57)	After scrubbing (1335, 12/11/57)
		Surface readings, mr/hr		
1	20	4	2.2	2
2	14	3	1.8	1.8
3	16	3	2	1.8
4	20	2	2	1.9
5	19	4	2	1.8
6	25	4	2.2	1.8
7	19	4	2.2	2.2
8	20	4	1.8	2.0
9	20	6	2.2	1.9
10	22			
11	18			
12	17			
13	11			
14	10			
15	11			
16	13			
17	20			
		3-ft readings, mr/hr		
1	15	4	3	3
2	8	4	2.5	2.5
3	9	3	3	3
4	14	4	2.8	2.9
5	10	4	3	2.9
6	20	5	2.6	2.7
7	14	4	3	2.8
8	12	4	3	2.8
9	13	5	2.4	2.3
10	21			
11	15			
12	14			
13	11			
14	10			
15	7			
16	10			
17	14			

TABLE 4.8—MEASUREMENTS ON COMPOSITION SHINGLE ROOF OF BUILDING B

Station	Before fire-hosing (1400, 12/10/57)	After fire-hosing (1510, 12/10/57)	After fire-hosing (1015, 12/11/57)	After scraping (1340, 12/11/57)
		Surface readings, mr/hr		
1	22	13	9	4
2	19	17	8	4
3	19	15	9	4
4	16	14	9	5
5	34	20	9	5
6	33	20	10	6
7	35	20	11	6
8	18	18	9	6
9	25	14	8	5
		3-ft readings, mr/hr		
1	21	15	9	4
2	20	17	8	4
3	22	18	9	4
4	22	20	10	5
5	25	17	10	5
6	27	20	10	6
7	26	19	11	6
8	15	15	10	6
9	24	16	7	6

TABLE 4.9—MEASUREMENTS TAKEN INSIDE BUILDING A*

Station	Before scraping (1450, 12/10/57)			After scraping NW section (1515, 12/10/57)			After scraping (1125, 12/11/57)			After fire-hosing roof (1300, 12/11/57)		
	Surface	3 ft	8 ft	Surface	3 ft	8 ft	Surface	3 ft	8 ft	Surface	3 ft	8 ft
1		1.0		0.9	1.0	2.0	0.05	0.2	0.5	0	0	0
2		3.2		2.3	2.8	2.9	0.3	0.3	0.5	0.2	0.2	0.4
3		4.5		2.0	2.5	2.4	0.4	0.6	0.6	0.3	0.4	0.9
4		8.0		1.2	2.0	3.0	0.4	0.4	0.7	0.2	0.2	0.4
5		2.8		1.0	1.5	2.1	0.4	0.2	0.4	0.1	0.1	0.2
6	1.6	3.2	5.0	1.2	2.3	3.7	0.25	0.4	0.6	0.1	0.4	0.4
7		9.0										
8		2.8	3.9									
9		4.2										
10		4.6										
11		2.0										

*Values are in milliroentgens per hour.

TABLE 4.10—MEASUREMENT OF FIELD DECAY

Date	Time	Surface, mr/hr	3-ft level, mr/hr	Ratio
12/10/57	1515	30	26	0.866
12/11/57	0930	15	12	0.800
12/11/57	1130	13	11	0.846
12/11/57	1330	11	10	0.909

TABLE 4.11—RATE OF APPLICATION OF DESCRIBED RECLAMATION PROCEDURES

Procedure	Equipment	Personnel	Area, sq ft	Time required	Rate,* sq ft/hr
Scraping (building A area)	1 motorgrader (8-ft blade)	1 operator	110,000	2.5 hr	45,000
Scraping (building B area)	1 motorgrader (8-ft blade)	1 operator	17,000	1.2 hr	14,000
Fire-hosing (composition shingle roof)	1 water truck w/pump, hose, and nozzle	1 tank-truck operator, 2 hose men	1,700	35 min	2,900
Fire-hosing (concrete-slab roof)	1 water truck w/pump, hose, and nozzle	1 tank-truck operator, 2 hose men	1,600	25 min	3,800
Scrubbing (concrete-slab roof)	10-in. brushes, detergent	3 men	1,600	12 min	2,700†

*Rates do not include delay times to fill tank truck, start equipment, etc.; they are for actual time spent in doing work.

†Rate per man.

TABLE 4.12—MEASUREMENTS OF AREA ABOUT BUILDING A BEFORE SCRAPING CORRECTED TO D+1

(Time: H + 25.0. Correction factor: 1.06)

	Row						
Station	1	2	3	4	5	6	7
			Surface readings,* mr/hr				
A			32	31	31		
B			35	34	33		
C	30	32	23	26	16	27	27
D	32	35	26	X	30	27	26
E	32	30	49	42	19	27	29
F			29	29	30		
G			29	28	30		
			3-ft readings,† mr/hr				
A			30	29	29		
B			31	29	29		
C	23	13?	21	17	13	26	15?‡
D	17?	28	32	X	14	26	26
E	26	26	34	28	20	14?	26
F			24	28	28		
G			27	27	27		

*Averages: A-B, 3-5: 32.7 mr/hr; C-E, 1-2: 31.8 mr/hr; C-E, 6-7: 27.2 mr/hr; E-F, 3-5: 29.2 mr/hr; of the 24: 30.2 mr/hr.

†Averages: A-B, 3-5: 29.5 mr/hr; C-E, 1-2: 25.8 mr/hr; C-E, 6-7: 26.0 mr/hr; E-F, 3-5: 26.8 mr/hr; of the 20: 27.2 mr/hr.

‡Not used in computing averages.

TABLE 4.13—MEASUREMENTS OF AREA ABOUT BUILDING A AFTER SCRAPING CORRECTED TO D+1

(Time: H + 47.0. Correction factor: 2.39)

	Row						
Station	1	2	3	4	5	6	7
			Surface readings, mr/hr				
A			24	14.3	4.8		
B			2.4	4.8	2.4		
C	14.3	4.8	9.6	4.8	2.4	4.8	11.9
D	9.6	14.3	7.2	X	9.6	4.8	9.6
E	29	4.8	9.6	7.2	4.8	4.8	11.9
F			4.8	7.2	35.8?		
			3-ft readings, mr/hr				
A			19.1	16.7	9.6		
B			4.8	7.2	4.8		
C	11.9	9.6	4.8	7.2	9.6	4.8	11.9
D	11.9	9.6	7.2	X	4.8	4.8	11.9
E	21.5	7.2	9.6	9.6	7.2	7.2	14.3
F			7.2	7.2	16.7?		

TABLE 4.14—MEASUREMENTS OF AREA ABOUT BUILDING B BEFORE SCRAPING CORRECTED TO D+1
(Time: H + 26.0. Correction factor: 1.13)

	Row						
Station	1	2	3	4	5	6	7
			Surface readings, mr/hr				
A			32	28	30		
B			29	29	32		
C	33	32	37	38	34	34	47
D	33	36	33	X	35	37	42
E	32	35	35	25	29	42	45
F			41	44	50		
G			50	47	47		
			3-ft readings, mr/hr				
A			28	26	28		
B			28	26	27		
C	28	30	25	23	25	33	41
D	29	32	25	X	21	34	38
E	29	33	29	25	24	36	43
F			37	37	38		
G			44	42	41		

TABLE 4.15—MEASUREMENTS OF AREA ABOUT BUILDING B AFTER SCRAPING CORRECTED TO D+1
(Time: H + 49.2. Correction factor 2.52)

	Row						
Station	1	2	3	4	5	6	7
			Surface readings, mr/hr				
A			30	30	30		
B			7.5	40?	20		
C	30	23	10	38?	15	13	45
D	35	5.0	7.5	X	5.0	30?	45
E	35	15	13	5.0	13	13	43
F			7.5	18	13		
G			50	50	45		
			3-ft readings, mr/hr				
A			28	25	25		
B			10	15	15		
C	28	13	10	13	13	15	40
D	28	10	10	X	7.5	20	40
E	28	15	13	10	15	20	43
F			13	10	23		
G			45	43	43		

TABLE 4.16—MEASUREMENTS ON CONCRETE-SLAB ROOF OF BUILDING A CORRECTED TO D+1

Station	Before scraping (H+?, 0.968)*	After scraping (H+47.5; 2.41)	After fire-hosing (H+49.0; 2.51)	After scrubbing (H+49.6; 2.54)
		Surface readings, mr/hr		
1	19.4	9.6	5.5	5.1
2	13.6	7.2	4.5	4.6
3	15.5	7.2	5.0	4.6
4	19.4	4.8	5.0	4.8
5	18.4	9.6	5.0	4.6
6	24.2	9.6	5.5	4.6
7	18.4	9.6	5.5	5.6
8	19.4	9.6	4.5	5.1
9	19.4	14.4	5.5	4.8
10	21.3			
11	17.4			
12	16.5			
13	10.6			
14	9.7			
15	10.6			
16	12.6			
17	19.4			
		3-ft readings, mr/hr		
1	14.5	9.6	7.5	7.6
2	7.7	9.6	6.3	6.4
3	8.7	7.2	7.5	7.6
4	13.6	9.6	7.0	7.4
5	9.7	9.6	7.5	7.4
6	19.4	12.0	6.5	6.9
7	13.6	9.6	7.5	7.1
8	11.6	9.6	7.5	7.1
9	12.6	12.0	6.0	5.8
10	20.3			
11	14.5			
12	13.6			
13	10.6			
14	9.7			
15	6.8			
16	9.7			
17	13.6			

*Correction factor for H+25.0 is 1.06; average ratio of comparable locations for data in Table 4.1 to that in Table 4.2 is 1.10; thus multiply by 1.06/1.10 or 0.968 to obtain appropriate correction for the instrument used.

TABLE 4.17—MEASUREMENTS ON COMPOSITION-SHINGLE ROOF OF BUILDING B CORRECTED TO D+1

Station	Before fire-hosing (H+26.0; 1.13)	After fire-hosing (H+27.2; 1.20)	After fire-hosing (H+46.2; 2.34)	After scraping (H+49.7; 2.55)
		Surface readings, mr/hr		
1	24.8	15.6	21.0	10.2
2	21.4	20.4	18.7	10.2
3	21.4	18.0	21.0	10.2
4	18.1	16.8	21.0	12.8
5	38.4	24.1	21.0	12.8
6	37.3	24.1	23.4	15.3
7	39.5	24.1	25.7	15.3
8	20.3	21.6	21.0	15.3
9	28.2	16.8	18.7	12.8
		3-ft readings, mr/hr		
1	23.7	18.0	21.0	10.2
2	22.6	20.4	18.7	10.2
3	24.8	21.7	21.0	10.2
4	24.8	24.1	23.4	12.8
5	28.2	20.4	23.4	12.8
6	30.5	24.1	23.4	15.3
7	29.4	22.9	25.7	15.3
8	16.9	18.0	23.4	15.3
9	27.1	19.2	16.4	15.3

TABLE 4.18—MEASUREMENTS TAKEN INSIDE BUILDING A CORRECTED TO D+1*

Station	Before scraping (H+26.8; 1.17)			After scraping NW section (H+27.2; 1.20)			After scraping (H+47.4; 2.41)			After fire-hosing roof (H+49.0; 2.51)		
	Surface	3 ft	8 ft	Surface	3 ft	8 ft	Surface	3 ft	8 ft	Surface	3 ft	8 ft
1		1.2		1.1	1.2	2.4	0.12	0.5	1.2	0	0	0
2		3.7		2.8	3.4	3.5	0.7	0.7	1.2	0.5	0.5	1.0
3		5.2		2.4	3.0	2.9	1.0	1.4	1.4	0.8	1.0	2.3
4		9.4		1.4	2.4	3.6	1.0	1.0	1.7	0.5	0.5	1.0
5		3.3		1.2	1.8	2.5	1.0	0.5	1.0	0.2	0.3	0.5
6	1.9	2.7	5.8	1.4	2.6	4.4	0.6	1.0	1.4	0.2	1.0	1.0
7		10.5										
8		3.3	4.6									
9		4.9										
10		5.4										
11		2.3										

*Values are given in milliroentgens per hour.

Chapter 5

TREATMENT OF THE DATA

5.1 GENERAL DISCUSSION

The data, as taken in the experiment, require only a correction to a common time owing to radioactive decay to express the results in terms of a residual number (ratio of radiation intensity after decontamination to that prior to decontamination; a more strict definition is given as the ratio of the dose after application of a countermeasure to potential dose where no countermeasure is used) for the operations carried out. If no errors exist in the measurements, the experimental residual numbers should vary from 0 to 1, depending on the location of the measurements. In general, the observed residual numbers will apply only to the described experiment and cannot be extrapolated to other levels of fallout, to other geometrical arrangements of radioactive sources, or to other houses of the same construction but of different size. Furthermore, these residual numbers are not a measure of the amount of fallout removed from the areas and surfaces by the decontamination procedures. The reason for these restrictions on the utility of the residual numbers is that each observed reading is a measure of the radiations originating from a large number of radiation sources and the majority of the sources are not located on the areas and surfaces that were treated.

If the true effectiveness of the reclamation procedures is to be determined, the total radiation at all locations must be divided into two parts: (1) the contribution from the radioactive sources in the areas and surfaces treated and (2) the contribution from radioactive sources outside these areas and surfaces. The mathematical notation is then

$$I(o) = I_A + I \tag{5.1}$$

where I(o) is the observed intensity (corrected to D + 1), I_A is the intensity from the areas and surfaces of interest, and I is that contributed from other sources. In most cases it is convenient to convert the data to either a measure of the source intensity per unit area, I_0, or to that for an equivalent infinite plane source, I_∞. The ratio of the later two quantities is designated as

$$\alpha = I_\infty / I_0 \tag{5.2}$$

Further relations between the above quantities are defined as follows:

$$p = I/I_\infty \tag{5.3}$$

and

$$q = 1 - p \tag{5.4}$$

and, in general,

$$I_\infty = I_A + I \tag{5.5}$$

so that I(o) is always associated with I_∞; hence

$$q = I_A / I_\infty \tag{5.6}$$

and

$$I_A = \alpha q I_0 \tag{5.7}$$

By definition, the decontamination ratio is

$$F = I_0^1 / I_0 \tag{5.8}$$

where I_0^1 is the source intensity per unit area after decontamination and I_0 is that prior to decontamination. At a given location within, or near, the treated area, q is the same before and after decontamination if the area is uniformly decontaminated; thus, if I'_A and I′(o) are the intensities after decontamination, then

$$F = \frac{I'_A}{I_A} = \frac{I'(o) - I}{I(o) - I} \tag{5.9}$$

It can be seen from Eqs. 5.1 and 5.9 that, if I is small compared with I_A, then F is simply I'_0/I_0; this value will be obtained if the reclaimed areas are sufficiently large or if sufficient shielding exists between the detector and the sources that contribute to I. For the large areas, the value of F is equal to the residual number.

The values of I for the experimental geometries are estimated in the following sections from the computations of C. F. Ksanda et al.[1] The computations are intended to bias the observed readings in the proper direction to give more realistic values of F than could otherwise be obtained from the observed data alone.

The remainder of this section deals with the treatment of the data. The treatments are in the order required to reduce the data to F values. The topics covered are:

1. Determination of the decay curve and computation of intensities at D + 1.
2. Determination of the "terrain factor" from the data for use in computation of p,q, and I.
3. Determination of variation of intensities with altitude.
4. Determination of scattered components p and q for the various monitoring stations used in the experiment.
5. Estimation of decontamination ratios for motorgrading the two areas.
6. Estimation of decontamination ratios for decontaminating the concrete roof of building A.
7. Estimation of decontamination ratios for decontaminating the composition roof of building B.
8. Estimation of shielding factors for building A.

5.2 DETERMINATION OF THE DECAY CURVE

It was intended that the measurements given in Table 4.10 would provide the necessary information for making the decay corrections. However, when the data were plotted, the log slope of the curve appeared to be too steep in comparison with previously observed decay data on fallout to be accepted for use. A number of repetitive measurements on and around building B were noted, and these were used to determine the decay curve. The decay from 26 hr to 46.2 hr is computed in Table 5.1, and from 26 hr to 49.2 hr, in Table 5.2. Because of an apparent gradient in the radiation field about building B, the readings were averaged by groups, as indicated by the station-number designation. In Table 5.3, for 27.2 hr to 46.2 hr, the roof readings on building B are used; the two sets of readings were taken after fire-hosing and before the area was scraped. If the value 0.542 is divided into 0.483, the value 0.891 is obtained for the decay from 26.0 to 27.2 hr. This manner of computing the decay includes any drift or change in calibration of the instruments when they are not used to measure the decay of the field independently. The intensity at 26 hr was arbitrarily adjusted to 30 mr/hr in plotting the curve in Fig. 5.1. The readings at the field decay station and a -1.2 log-slope line are given for comparison. The readings at the field decay station at the later times may have been influenced by the scraped area at building A (i.e., it may not have been far enough away) or the field about it may have been disturbed by the passage of vehicles between the two buildings.

The smoothed values of the decay correction factors are summarized in Table 5.4; the given values were used to correct all the observed survey measurements to D + 1. The results are tabulated in Tables 4.12 through 4.18.

5.3 DETERMINATION OF THE TERRAIN FACTOR FROM THE DATA

The methods of accounting for the effect of terrain on the radiation intensity presented in Ref. 1 are: (1) mixing of the sources with soil to a depth Z and (2) burial of the sources of a depth Z. In the computations to follow, the functions given in that reference for uniform mixing will be used. The depth of the mixture, Z, can be determined from radiation measurements taken at several different heights above an extended source. The computations in Ref. 1 are for a photon energy of 1.25 Mev; this energy is higher than the mean photon energy of fission-product photons, which is between 0.5 and 0.6 Mev at the times of interest.[2] If all the real linear dimensions are multiplied by 1.5, which is the ratio of linear absorption coefficients in air for 0.5-Mev and 1.25-Mev photons, the effect on the computations is to increase the source energy from about 0.5 to 1.25; conversely, if the linear dimensions associated with a given parameter in Ref. 1 are reduced by $^2/_3$, the effect on the computation is to decrease the photon energy for the desired effect from 1.25 Mev to about 0.5 Mev. Although this type scaling is not exact, it will not be in large error, especially for photon energies whose attenuation by air and sand is due mainly to Compton scattering and where the scattering build-up factor does not vary significantly with photon energy. In such a case, differences in the linear absorption coefficients vary almost linearly with differences in the photon energy; thus the ratio of the absorption coefficients at the two energies can be used as a linear scale factor on the depth of mixing, Z, the height of the measurement, h, and the dimensions of a contaminated slab (radius, R_0, or sides of a rectangle ($2a \times 2b$). The values of Z, p, and q for this change in linear dimensions with photon energy will then remain constant. Thus, for the 3-ft readings, the height to enter the tables in Ref. 1 is 4.5 ft or 1.37 meters.

As a first step in determining Z for the measurements, $\alpha(h^1)/\alpha(o)$ was computed from the α values given in Ref. 1 at Z^1 values of 0.5, 1.0, and 3.0 in. (using primed notation for tabular dimensions and unprimed for real dimensions). The values are plotted as a function of height in Fig. 5.2 and are tabulated in Table 5.5. The values at 1.37 meters were read from the curves.

At an h^1 of 1.37 meters, the three values of log $\alpha(h^1)/\alpha(o)$ vary linearly with $1/Z^1$; the relation is given by

$$\log \frac{\alpha(1.37^1)}{\alpha(o)} = -0.0187 - \frac{0.0135}{Z^1} \tag{5.10}$$

Hence by determining $\alpha(h^1)/\alpha(o)$ from the ratio of the 3-ft readings to the surface readings, the appropriate value of Z can be determined from Eq. 5.10. The computations are summarized in Table 5.6; the readings near the buildings and the questioned readings were not used. When the average value, 0.882, of $\alpha(1.37^1)/\alpha(o)$ is substituted into Eq. 5.10, the computed value of Z^1 is 0.38 in.; the real value of Z is therefore 0.25 in. These values of Z and Z^1 will be used in all the computations. For concrete or other smooth surfaces, the value of Z should be less than for a land surface; unfortunately, it is impossible to determine the value of Z for the concrete slab roof from the data (as will be seen later); so the above value was used.

5.4 VARIATION OF RADIATION INTENSITY WITH ALTITUDE

With the value of Z determined in the previous paragraph and the values of α at other values of Z^1 and h^1 in Ref. 1, the values of α at Z^1 equal to 0.38 were determined at several values of h^1. These are plotted in Fig. 5.3. The value at $h = 0$ was determined by dividing the value of α at 3 ft by 0.882, and it therefore corresponds to the observed surface readings. The values of α for some of the monitor stations are given in Table 5.7; these are used in later computations. It may be noted that $\alpha(I_\infty/I_0)$ decreases with altitude; so for a constant value of I_0 (source intensity per unit area), I_∞ decreases with height above the surface.

5.5 ESTIMATION OF p AND q VALUES FOR VARIOUS MONITORING STATIONS

The first major alteration of the radiation field in the exercise occurred when the area around building A was scraped out to a square of dimensions 340 ft by 340 ft. In computing the contributions of the sources outside this area (disregarding the shielded source on top of the slab) to the monitor stations, the methods of Ref. 1 were used to estimate p and q (see Eqs. 5.3 through 5.6) at stations A4, G4, D1, and D7 (all the same); B4, F4, D2, and D6 (all the same); the center of the building roof; the corners of the slab; and the mid points of each side of the slab. The computational station lay-out and distances for the area are shown in Fig. 5.4. The stations are numbered from 1 to 6. The semi-width of a rectangular cleared area is designated as b, its semi-length as a, and the value of the ratio q as $q(a',b')$. To initiate the computations, all the dimensions were multiplied by 1.5 and converted to meters; the values of q for each point were then determined as a function of height by use of the graphs and tables of Ref. 1. In notational form, q_i for each station as determined from Fig. 5.4 is:

$q_1 = q(77.7,77.7)$; $a/b = 1.00$
$q_2 = 1/2\,[q(77.7,34.3) + q(121,77.7)]$; $a/b = 2.27, 1.56$
$q_3 = 1/2\,[q(85.3,77.7) + q(77.7,70.2)]$; $a/b = 1.10, 1.11$
$q_4 = 1/2\,[q(88.7,77.7) + q(77.7,66.8)]$; $a/b = 1.14, 1.16$
$q_5 = 1/4\,[q(70.2,66.8) + q(85.3,66.8) + q(88.7,85.3) + q(88.7,70.2)]$; $a/b = 1.05, 1.28, 1.04, 1.26$
$q_6 = 1/2\,q(156,77.7)$; $a/b = 2.00$

The results of the computation are given in Table 5.8 and are plotted in Fig. 5.5. It may be noted that, as h increases (1/h decreases), p increases and approaches the value of 1.0. For a given source strength I_0, I ($=p\alpha I_0$) over a perfectly cleared area first increases with height and after a certain height begins to decrease again; this follows from the fact that α decreases with height (see Fig. 5.3) and p increases with height up to a value of 1.0. The variation of p from the center of the cleared area to the mid point of the sides is given in Fig. 5.6.

The variation of p with 1/h at the center of the circular scraped area around building B, radius of 75 ft, is given in Fig. 5.7; the variation of p at 3 ft with distance from the center is shown in Fig. 5.8. The radioactive sources on the ground contributing to the measurements taken on top of the concrete-slab roof of building A are shielded owing to a shadow cast by the building and roof; this shielding shadow has the effect of a "cleared area" for the stations of the roof. Taking the surface of the roof as 9 ft above surface, and assuming zero transmission of photons from sources within the shadow, it is found that the shielding shadow for the 3-ft readings at all locations covers an area on the ground 192 ft long by 132 ft wide. The contributions to the radiation from sources outside the shadowed area to the center of the roof, the corners of the roof, and the mid point of each side are given in Fig. 5.9. The contributions of the unshadowed sources on the ground to the surface readings will be computed later.

The shielding shadows for the roof stations on building B are shown in Figs. 5.10 and 5.11. These shadows indicate that certain locations on structures are less "exposed" to radiations from some distant sources than from others. The surface measurements along the roof peak, for example, are shielded to an infinite distance in the horizontal plane along the direction of the roof peak. The contributions from sources on the ground outside the shielding shadow of building B are given in Table 5.9 for the monitor stations. In each location, the contribution to the surface reading is the smaller of the two.

The contribution of the sources on the concrete slab itself to the readings at the center of the slab, at each corner, and at the centers of each side are given according to station number in Table 5.10. The computations for the surface readings were made for a height of 2 in. It was unnecessary to make similar computations for the roof of building B.

The values of q for the surface readings in Table 5.10 for the concrete roof were used, along with the data in Table 4.16, to estimate values of p for the roof shielding shadow. Since the data in the first column of Table 4.16 were not all taken at the same stations as the remainder of the data, the q values of Table 5.10 were linearly interpolated to the locations of the measured values. The contributions from sources on the ground to locations near the center of the slab were taken to be zero. The computations are given in Table 5.11; the value of I_∞ at 9 ft given in the table was taken from Sec. 5.6. The average values of $p(I/I_\infty)$ are summarized and back-extrapolated to the original locations for q (Table 5.10) in Table 5.12.

The values of p, q, and α determined in this section are used in the following sections to aid in correcting the data in the appropriate direction so as to provide estimates of the decontamination ratios from the experimental data.

5.6 ESTIMATION OF DECONTAMINATION RATIOS FOR MOTORGRADING

The average surface reading (I_∞) about building A before grading, not taking into account those readings close to the building, was 30.2 mr/hr at 1 day; the value of α (Table 5.7) at this height is 1.73; hence I_0 is 17.4 mr/hr.

For the 3-ft readings the average value of I_∞ was 27.2 and, with a value of α 1.53, the computed value of I_0 is 17.8 mr/hr. With the average of 17.6 mr/hr for I_0, the adjusted average values of I_∞ are 30.5 mr/hr at 1 day for the surface readings and 26.9 mr/hr at 1 day for the 3-ft readings.

If the magnitude of the radiation field around building B is assumed to vary linearly with distance from the building, the average value of the readings before grading would be representative of the point at the center of the area. For the average of 37.8 mr/hr at 1 day for the surface readings, I_0 is 21.8 mr/hr. The 3-ft average of 33.7 mr/hr at 1 day gives 22.0 mr/hr for I_0. With use of the average value 21.9 mr/hr, the adjusted average values of I_∞ are 37.9 mr/hr at 1 day for the surface readings and 33.5 mr/hr at 1 day for the 3-ft readings. The ratio of the average I_0 value at building B to that at building A is 1.24; thus the area at building B received 24 per cent more fallout than that at building A.

The residual numbers for motorgrading around building A are summarized in Table 5.13; those for motorgrading around building B are given in Table 5.14. The residual numbers are the ratio of the decay-corrected readings taken after scraping to the decay-corrected readings taken before scraping. The lower effectiveness (higher residual number) for scraping around building B was due to a combination of the rougher surface of the soil, more construction items (small concrete blocks, etc.) dispersed around the area, and the fact that the area scraped was small. However, for the 3-ft readings, this means that the shielding provided by the building contributed to a greater extent to the readings than did building A shielding. This is shown by the ratio of the 3-ft residual numbers to the surface residual numbers; for the building A area the ratio is 1.45, and for the building B area it is 1.35. In the previous section, no computations were made to determine the effect of the building shielding shadows on the ground surface and 3-ft readings. The effect on the surface readings should be relatively small.

The average of the surface readings out to about 95 ft from the center of building A after scraping is 6.06 mr/hr at 1 day. The average residual number defined as $\bar{I}'_\infty/\bar{I}_\infty$ is 6.06/30.5, or 0.199; this value will be taken as equal to the decontamination ratio, F, for the scraping by motorgrader. The corresponding value of I_0' is 3.50 mr/hr.

Owing to the gradient in the fallout around building B, the average value of the surface readings before and after scraping were not used to compute F; the value 0.341 from an average of the individual ratios (out to 65 ft), however, will be retained as the measure of F from the surface readings for that area. The corresponding value of I_0' is 0.341 × 21.9, or 7.47 mr/hr.

The computations of I, I'_A, and I'_∞ for the 3-ft readings taken after scraping the area around building A are given in Table 5.15. The values of p were taken from Fig. 5.6; the same value of p was used for all the locations near 95 ft away from the center and another single value for those near the edge of the area. The shielding of the building was neglected in the computations; however, the effect of the shielding would be larger in converting I'_A to I'_∞ than in the computation of I'_A. The average value, 6.04 mr/hr at 1 day, of I'_∞ gives an I'_0 value of 3.95 mr/hr and an F value of 0.222. These are in satisfactory agreement with values obtained directly from the surface measurements. The average value of I'_0 for the two sets of data is 3.72 mr/hr; this combination of data gives a decontamination ratio value of 3.72/17.6, or 0.211.

The computation of F for the 3-ft readings taken after scraping the area around building B is given in Table 5.16. Owing to the gradient in the field, the computations in Table 5.16 were made differently than those in Table 5.15. The individual initial measurement values (Table 4.14) were used to compute I, and the ratio was used to compute F. The average value of the latter, 0.265, is lower than that obtained from the surface readings. The weighted mean value for the two sets of data is 0.300; this value of F leads to the value 6.57 mr/hr for I'_0.

5.7 ESTIMATION OF DECONTAMINATION RATIOS FOR CONCRETE ROOF OF BUILDING A

The variation of I_∞ and I'_∞ with height above the ground is given in Table 5.17 using the values of I_0 and I'_0 determined in the previous paragraphs.

From the data in Chap. 4, the average of the initial surface reading on the concrete roof was 16.8 mr/hr at 1 day; after fire-hosing it was 5.11 mr/hr at 1 day; and after scrubbing it was 4.87. The respective residual numbers for the processes are therefore 0.54, 0.30, and 0.29. The residual numbers for the 3-ft readings for the same processes are 0.74, 0.52, and 0.52. The difference in the values at the two heights reflect the fact that the 3-ft readings were exposed to more radiation from sources on the ground.

The initial source level on the concrete roof is estimated in Table 5.18 using the values of p and q determined in Sec. 5.3. In computing the appropriate values of I_∞, the ground-surface source intensity I_0 was taken as 3.72 mr/hr over the whole area (scraped plus unscraped), and from areas outside the scraped area the ground-surface source intensity I_0 was an additional 17.6 − 3.7, or 16.9 mr/hr. The source level on the roof remaining after fire-hosing is estimated in Table 5.19; and the level after scrubbing is estimated in Table 5.20. It may be noted that an error of a few tenths of a milliroentgen per hour in the estimate of I, especially for the 3-ft readings, is magnified by a factor as large as 5 in the estimate of I'_∞. The values of I'_∞ at 3-ft for the corners of the roof are consistently high in Tables 5.19 and 5.20.

5.8 ESTIMATION OF DECONTAMINATION RATIOS FOR COMPOSITION ROOF OF BUILDING B

Because of the gradient in the field around building B, three average ground-source intensities were used in the computations; the values of $\bar{I}_0$ for each side of house and the average for both sides are given in Table 5.21. The values of I_∞ at the appropriate heights above the surface of the ground for each value of I_0 are given in Table 5.22.

The initial contributions of the sources on the roof of building B at each station is estimated in Table 5.23; that after fire-hosing is estimated in Table 5.24 along with values of F for the procedure. In these computations, the estimate of F was made in two ways. One was by the ratio of the individual I'_A/I_A ratios and the other by the ratio of the two sums. The latter method gives highest weight to the larger values in each sum. The estimation of F from the second set of measurements before scraping the area is given in Table 5.25. The values of I_∞ at the heights of the monitor stations on the roof of building B after the area around the house had been scraped are computed in Table 5.26; the values are used in Table 5.27 to estimate the source levels on the roof of building B from the readings taken after the area was scraped. From the six pairs of F values, the grand average value from the individual ratios is 0.347; that from the ratio of the sums is 0.340.

5.9 ESTIMATION OF SHIELDING RESIDUAL NUMBERS FOR BUILDING A

The meaning of a shielding factor in terms of the shielding residual number for a building will not be discussed; the residual number is defined as the ratio of the reading at a given monitor station in the building to the outside infinite field reading at 3 ft above the surface. Table 5.28 gives the shielding residual numbers computed on this basis. The high numbers for Stations 4 and 7 are the result of their being taken behind wood panels. A more complete set of measurements was not taken in other rooms because the panels were broken out and the interiors could have been contaminated to an unknown amount. The same situation pertained to all rooms in building B. The outside of the room is shown to the right in Fig. 5.12, in which two wood panels, one on each side of the room, can be seen.

According to *The Effects of Nuclear Weapons*,[3] the half-thickness of concrete and wood for fission-product gamma rays is 2.2 in. and 8.8 in., respectively. With these half-thickness values for fission products deposited directly on these surfaces, the fraction of the gamma radiation passing through 6 in. of concrete would be 0.15, and the fraction passing through 1.5 in. of wood would be 0.85. However, the same reference gives 0.22 cm^{-1} for the absorption coefficient for 0.5-Mev photons incident on concrete; this value would lead to a transmission fraction of 0.035 through 6 in. of concrete (and less for a lower photon energy). Since the source energy of the photons is about 0.5 Mev on the average, the average energy of the photons incident on the surface of the building walls should be somewhat less. However, the situation is complicated by the presence of fallout on the roof (also small amounts on the outside of the walls). It may be noted that after fire-hosing, the shielding residual numbers vary between 0.03 and 0.15 for monitor stations near the outer walls; this variance in the data is of the same range of uncertainty as that obtained from Ref. 3 for a much simpler geometry.

Residual numbers for the outside reclamation procedures as derived from the shielding data are given in Table 5.29; they were computed for the 3-ft readings by taking the ratio of the reading after the stated process to the initial reading at that station. The average residual number for the complete reclamation procedure for all stations was 0.14. For the center of the room where the average shielding residual number itself was 0.13, the combined residual number for shielding plus reclamation is 0.14×0.13, or 0.018. Thus, even though the individual residual numbers for each countermeasure were not particularly low, the combination of the shielding and decontamination countermeasures gives a reduction of the gamma radiation of a fairly large amount.

REFERENCES

1. C. F. Ksanda, S. M. Cohn, E. S. Shapiro, A. Moskin, and H. C. Schmidt, Gamma Radiations from Contaminated Planes and Slabs, Report USNRDL-TM 27, 1955.
2. C. F. Miller, Gamma Decay of Fission Products from the Slow-neutron Fission of U^{235}, Report USNRDL-TR-187, July 1957.
3. "The Effects of Nuclear Weapons," Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C., 1957.

TABLE 5.1—COMPUTATION OF DECAY FROM 26 HR TO 46.2 HR

Station	I_1(s) (H+26)	I_2(s) (H+46.2)	I_2(s)/I_1(s)	I_1(3 ft) (H+26)	I_2(3 ft) (H+46.2)	I_2(3 ft)/I_1(3 ft)
A,B4	25.5	12.0	0.470	23.0	10.5	0.457
D1,2	30.5	14.5	0.475	27.0	11.5	0.426
D6,7	35.0	18.5	0.528	32.0	16.5	0.516
F,G4	40.5	21.0	0.518	35.0	16.5	0.471
Average	32.9	16.5	0.498	29.2	13.8	0.468
			(0.498 + 0.468)/2 = 0.483			

TABLE 5.2—COMPUTATION OF DECAY FROM 26 HR TO 49.2 HR

Station	I_1(s) (H+26)	I_2(s) (H+49.2)	I_2(s)/I_1(s)	I_1(3 ft) (H+26)	I_2(3 ft) (H+49.2)	I_2(3 ft)/I_1(3 ft)
A3,4,5	26.7	12.0	0.449	24.3	10.3	0.424
C,D,E1	28.7	13.3	0.463	25.7	11.0	0.428
G3,4,5	42.7	19.3	0.452	37.3	17.3	0.464
C,D,E7	39.7	17.7	0.446	36.0	16.3	0.453
Average	34.4	15.6	0.452	30.8	13.7	0.442
			(0.452 + 0.442)/2 = 0.447			

TABLE 5.3—COMPUTATION OF DECAY FROM 27.2 HR TO 46.2 HR

Station	I_1(s) (H+27.2)	I_2(s) (H+46.2)	I_2(s)/I_1(s)	I_1(3 ft) (H+27.2)	I_2(3 ft) (H+46.2)	I_2(3 ft)/I_1(3 ft)
1	13	9	0.69	15	9	0.60
2	17	8	0.47	17	8	0.47
3	15	9	0.60	18	9	0.50
4	14	9	0.64	20	10	0.50
5	20	9	0.45	17	10	0.59
6	20	10	0.50	20	10	0.50
7	20	11	0.55	19	11	0.53
8	18	9	0.50	15	10	0.67
9	14	8	0.57	16	7	0.44
Average	16.8	9.1	0.552	17.4	9.3	0.533
			(0.552 + 0.533)/2 = 0.542			

TABLE 5.4—TABULATION OF SMOOTHED VALUES OF DECAY CORRECTION FACTORS

t, H+hr	I(arb)	Correction factor to H+24.0 hr
24	33.9	1.000
25	31.8	1.06
26	30.0	1.13
27.2	28.2	1.20
46.25	14.5	2.34
47.0	14.2	2.39
47.5	14.1	2.41
49.0	13.52	2.51
49.2	13.47	2.52
49.58	13.32	2.54
49.67	13.27	2.55

TABLE 5.5—TABULATION OF $\alpha(h^1)/\alpha(o)$ AT SEVERAL VALUES OF Z^1 AND h^1

		Z^1	
h^1, meters	0.5 in.	1.0 in.	3.0 in.
0	1.00	1.00	1.00
0.5	0.950	0.968	0.979
1.0	0.919	0.944	0.961
1.37	0.900	0.928	0.948
5.0	0.769	0.817	0.867
10.0	0.656	0.716	0.784

TABLE 5.6—COMPUTATION OF α $(1.37^1)/\alpha(o)$ FROM DATA IN CHAPTER 4

	Row						
Station	1	2	3	4	5	6	7
				From Table 4.1			
A	0.867	0.882	0.857	0.075	0.871	0.923	0.781
B	0.853	0.824	0.867		0.828	0.821	0.926
C	0.833	0.917				0.828	0.893
D				X			
E	0.882	0.818				0.862	0.897
F	0.882	0.844	0.900	0.867	0.896	0.893	0.853
G	0.789	0.853	0.771	0.967	0.931	0.967	0.806
Total = 30.324; average = 0.866 (35 pairs)							
				From Table 4.2			
A			0.933	0.931	0.931		
B			0.879	0.844	0.871		
C	0.714					0.960	
D		0.788		X		0.960	1.000
E	0.800	0.857					0.889
F			0.852	0.963	0.928		
G			0.926	0.962	0.893		
Total = 17.881; average = 0.894 (20 pairs)							
				From Table 4.4			
A			0.893	0.920	0.926		
B			0.962	0.885	0.857		
C	0.862	0.964				0.967	0.857
D	0.897	0.875		X		0.909	0.918
E	0.928	0.935				0.865	0.950
F			0.917	0.846	0.772		
G			0.886	0.738	0.857		
Total = 21.386; average = 0.891 (24 pairs)							
Grand average = 0.882							

TABLE 5.7—VALUES OF α FOR MONITOR STATIONS AT SEVERAL VALUES OF h

h, ft	α	Station
0	1.73	Surface readings: ground and concrete slab
3	1.53	3-ft readings: ground and concrete slab
9	1.34	Surface readings on concrete slab
11.3	1.28	Surface readings at edge of roof of building B
12	1.27	3-ft readings above concrete slab
14.3	1.22	3-ft readings at edge of roof of building B
16.5	1.18	Surface readings on peak of roof of building B
19.5	1.13	3-ft readings on peak of roof of building B

TABLE 5.8—SUMMARY OF COMPUTATIONS FOR CONTRIBUTION TO RADIATION AT DESIGNATED STATIONS FROM SOURCES DISTRIBUTED ON PLANE AREA OUTSIDE THE 340- BY 340-FT SCRAPED AREA*

h^1	p_1	p_2	p_3	p_4	p_5	p_6
1 meter	0.024	0.040	0.024	0.025	0.025	0.508
6 ft	0.045	0.079	0.045	0.046	0.046	0.513
5 meters	0.119		0.120	0.120	0.122	
10 meters	0.184		0.198	0.198	0.201	

*$p_i = 1-q_i$, Z = 0.25, E = 0.5 Mev.

TABLE 5.9—VALUES OF I/I_∞ FROM SOURCES ON GROUND SURFACE OUTSIDE THE SHIELDING SHADOW OF BUILDING B AT MONITOR STATIONS

Stations	Surface	3-ft	Location
1	0.75	0.80	Corner of roof
2	0.50	0.60	Center, roof edge
3	0.75	0.80	Corner of roof
4	0.70	0.75	End, roof peak
5	0.75	0.80	Corner of roof
6	0.50	0.60	Center, roof edge
7	0.75	0.80	Corner of roof
8	0.70	0.75	End, roof peak
9	0.40	0.55	Center, roof peak

TABLE 5.10—CONTRIBUTION OF SOURCES DEPOSITED ON CONCRETE-SLAB ROOF TO RADIATION AT MONITOR STATIONS

	q (= I_A/I_∞)		
Station	Surface*	3-ft	Location
1	0.257	0.192	Corner
2	0.547	0.330	Center, long side
3	0.257	0.192	Corner
4	0.544	0.307	Center, short side
5	0.257	0.192	Corner
6	0.547	0.330	Center, long side
7	0.257	0.192	Corner
8	0.544	0.307	Center, short side
9	0.920	0.600	Center of slab

*Height taken as 2 in.

TABLE 5.11—ESTIMATION OF CONTRIBUTION OF SOURCES OUTSIDE SHIELDING SHADOW TO SURFACE READINGS ON CONCRETE-SLAB ROOF OF BUILDING A

	I(o)	q_1	I'_∞	I_A	I	I/I_∞
1	19.4	0.257		5.6	13.8	0.58
2	13.6	0.402		8.7	4.9?	0.21
3	15.5	0.402		8.7	6.8?	0.29
4	19.4	0.257		5.6	13.8	0.58
5	18.4	0.400		8.6	9.8	0.42
6	24.2	0.400		8.6	15.6	0.66
7	18.4	0.257		5.6	12.8	0.54
8	19.4	0.402		8.7	10.7	0.45
9	19.4	0.402		8.7	10.7	0.45
10	21.3	0.257		5.6	15.7	0.67
11	17.4	0.400		8.6	8.8	0.37
12	16.5	0.400		8.6	7.9	0.33
13	10.6	0.50	21.2	10.8	0	0
14	9.7	0.50	19.4	10.8	0	0
15	10.6	0.50	21.2	10.8	0	0
16	12.6	0.50	25.2	10.8	0	0
17	19.4	0.92	21.1	19.9	0	0

$I_\infty = 23.6$; average $I'_\infty = 21.6$; $I_0 = 12.5$.

TABLE 5.12—SUMMARY OF I/I_∞ VALUES FOR SURFACE READINGS ON THE CONCRETE-SLAB ROOF

q	$\bar{I}$	p
0.257	14.0	0.593
0.400	10.7	0.453
0.402	10.5	0.445
0.544		0.313
0.547		0.297

TABLE 5.13—RESIDUAL NUMBERS FOR SCRAPING THE AREA ABOUT BUILDING A

	Row						
Station	1	2	3	4	5	6	7
			Surface readings				
A			0.750	0.461	0.155		
B			0.069	0.141	0.073		
C	0.476	0.150	0.417	0.185	0.150	0.178	0.441
D	0.300	0.409	0.277	X	0.320	0.178	0.369
E	0.906	0.160	0.196	0.172	0.253	0.178	0.410
F			0.166	0.248			
G			Average (to 95 ft) = 0.206				
			3-ft readings				
A			0.636	0.582	0.331		
B			0.155	0.248	0.166		
C	0.518		0.229	0.424	0.738	0.185	
D		0.343	0.225	X	0.343	0.185	0.458
E	0.827	0.277	0.282	0.257	0.360		0.550
F		0.300	0.300				
G			Average (to 95 ft) = 0.298				

TABLE 5.14—RESIDUAL NUMBERS FOR SCRAPING THE AREA ABOUT BUILDING B

	Row						
Station	1	2	3	4	5	6	7
			Surface readings				
A			1.0	1.0	1.0		
B			0.258		0.625		
C	1.0	0.719	0.270		0.441	0.382	1.0
D	1.0	0.139	0.227	X	0.143		1.0
E	1.0	0.429	0.371	0.200	0.448	0.310	1.0
F			0.171	0.409	0.260		
G			1.0	1.0	1.0	Average (to 65 ft) = 0.341	
			3-ft readings				
A			1.0	1.0	1.0		
B			0.357	0.577	0.556		
C	1.0	0.433	0.400	0.565	0.520	0.455	1.0
D	1.0	0.312	0.400	X	0.357	0.588	1.0
E	1.0	0.454	0.448	0.400	0.625	0.556	1.0
F			0.351	0.270	0.605		
G			1.0	1.0	1.0	Average (to 65 ft) = 0.461	

TABLE 5.15—COMPUTATION OF I, I'_A, AND I'_∞ FOR THE 3-FT READINGS TAKEN AFTER SCRAPING THE AREA ABOUT BUILDING A

	Row						
Station	1	2	3	4	5	6	7
			I,* mr/hr at 1 day				
A			15.0	15.0	15.0		
B			1.7	1.7	1.7		
C	13.1	1.5	1.0	1.0	1.0	1.5	13.3
D	13.1	1.5	0.9	X	0.9	1.5	13.3
E	13.1	1.5	0.9	0.9	0.9	1.5	13.3
F			1.5	1.5	1.5	1.5	
G			13.7	13.7	13.7		
			I'_A,† mr/hr at 1 day				
A			4.1	1.7	0		
B			3.1	5.5	3.1		
C	0	8.1	3.8	6.2	8.6	3.3	0
D	0	8.1	6.3	X	3.9	3.3	0
E	8.4	5.7	8.7	8.7	6.3	5.7	1.0
F			5.7	5.7			
			I'_∞,‡ mr/hr at 1 day				
A							
B			3.3	5.8	3.3		
C		8.6	3.9	6.4	8.9	3.5	
D		8.6	6.5	X	4.0	3.5	
E		6.0	9.0	9.0	6.5	6.0	
F			6.0	6.0			
Average = 6.04							

*For A-B, 3-5: $I_\infty = 29.5$; for C-E, 1-2: $I_\infty = 25.8$; for C-E, 6-7: $I_\infty = 26.0$; for F-G, 3-5: $I_\infty = 26.8$. p = 0.510 at 170 ft, 0.057 at 95 ft, and 0.034 at locations near the structure. $I = pI_\infty$.

†$I'_A = I'(o) - I$.

‡$I'_\infty = I'_A/q$; q = 1-p.

TABLE 5.16—COMPUTATION OF DECONTAMINATION RATIO FOR THE 3-FT READINGS TAKEN AFTER SCRAPING THE AREA ABOUT BUILDING B

	Row						
Station	1	2	3	4	5	6	7
$p = I/I_\infty$							
A			1.00	1.00	1.00		
B			0.33	0.33	0.33		
C	1.00	0.33	0.156	0.141	0.156	0.33	1.00
D	1.00	0.33	0.150	X	0.150	0.33	1.00
E	1.00	0.33	0.156	0.141	0.156	0.33	1.00
F			0.33	0.33	0.33		
G			1.00	1.00	1.00		
$I = pI_\infty$, mr/hr at 1 hr							
A							
B			9.3	8.6	9.0		
C		10.0	3.9	3.2	3.9	11.0	
D		10.6	3.8	X	3.2	11.3	
E		11.0	4.5	3.5	(4.7)	12.0	
F			12.3	12.3	12.6		
$I'_A = I'(o) - I$							
A							
B			0.7	6.4	6.0		
C		3.0	6.1	9.8	9.1	4.0	
D		0	6.2	X	4.3	8.7	
E		4.0	8.5	6.5	10.3	8.0	
F		0	0.7	0	10.4		
$q = 1 - p$							
A							
B			0.67	0.67	0.67		
C		0.67	0.844	0.859	0.844	0.67	
D		0.67	0.850	X	0.850	0.67	
E		0.67	0.844	0.859	0.844	0.67	
F			0.67	0.67	0.67		
$I'_\infty = I'_A/q$							
A							
B			1.0	9.5	8.9		
C		4.5	7.1	11.4	10.8	6.0	
D		0.0	7.3	X	5.1	13.0	
E		6.0	10.1	7.6	12.2	11.9	
F			1.1	0.0	15.5		
$F = I'_\infty/I_\infty$							
A							
B			0.036	0.365	0.330		
C		0.150	0.284	0.496	0.432	0.182	
D		0.0	0.292	X	0.243	0.382	
E		0.182	0.348	0.304	0.508	0.331	
F			0.027	0.0	0.408		

Average = 0.265

TABLE 5.17—VARIATION OF I_∞ AND I'_∞ WITH HEIGHT FOR I_0 VALUES OF 17.6 MR/HR AND 3.72 MR/HR, RESPECTIVELY

h, ft	I_∞, mr/hr at 1 day	I'_∞, mr/hr at 1 day
0	30.5	6.44
3	26.9	5.70
9	23.6	4.99
12	22.4	4.73

TABLE 5.18— ESTIMATION OF INITIAL SOURCE LEVEL ON CONCRETE-SLAB ROOF OF BUILDING A (Values of I(o), I, I'_A, I'_∞, and I'_0 in mr/hr at 1 day)

Surface readings

	I(o)	p	I	I'_A	q_1	I'_∞
1	9.6	0.59	4.1	5.5	0.257	21.4
2	7.2	0.31	2.1	5.1	0.547	9.3?
3	7.2	0.59	4.1	3.1	0.257	12.1?
4	4.8	0.30	2.1	2.7	0.544	5.0?
5	9.6	0.59	4.1	5.5	0.257	21.4
6	9.6	0.31	2.1	7.5	0.547	13.7
7	9.6	0.59	4.1	5.5	0.257	21.4
8	9.6	0.30	2.1	7.6	0.544	14.0
9	14.4	0	0	14.4	0.92	15.7

$I_\infty = 0.103\ (23.6-5.0) + 4.99 = 6.91$; average $I'_\infty = 17.9$; $I'_0 = 10.4$

3-ft readings

	I(o)	p_1	I_1	I_2	I	I'_A	q_1	I'_∞
1	9.6	0.777	3.68	2.34	6.0	3.6	0.192	18.8
2	9.6	0.625	2.96	2.30	5.3	4.3	0.330	13.0
3	7.2	0.777	3.68	2.34	6.0	1.2	0.192	6.2?
4	9.6	0.677	3.20	2.30	5.5	4.1	0.307	13.4
5	9.6	0.777	3.68	2.34	6.0	3.6	0.192	18.8
6	12.0	0.625	2.96	2.30	5.3	6.7	0.330	20.3
7	9.6	0.777	3.68	2.34	6.0	3.6	0.192	18.8
8	9.6	0.677	3.20	2.30	5.5	4.1	0.307	13.4
9	12.0	0.317	1.50	2.27	3.8	8.2	0.60	13.7

Average $I'_\infty = 16.3$; $I'_0 = 10.6$

$I_1 = p_1\ 4.73$
$I_2 = 0.128(22.4-4.7) = 2.27$
$0.130(22.4-4.7) = 2.30$
$0.130(22.4-4.7) = 2.30$
$0.132(22.4-4.7) = 2.34$

TABLE 5.19—ESTIMATION OF SOURCE LEVEL ON CONCRETE SLAB AFTER FIRE-HOSING

(Values of I(o), I, I'_A, and I'_∞ are in mr/hr at 1 day)

	I(o)	I	I'_A	q_1	I'_∞
		Surface readings			
1	5.5	4.1	1.4	0.257	5.4
2	4.5	2.1	2.4	0.547	4.4
3	5.0	4.1	0.9	0.257	3.5
4	5.0	2.1	2.9	0.544	5.3
5	5.0	4.1	0.9	0.257	3.5
6	5.5	2.1	3.4	0.547	6.2
7	5.5	4.1	1.4	0.257	5.4
8	4.5	2.1	2.4	0.544	4.4
9	5.5	0	5.5	0.92	6.0
Average $I'_\infty = 4.90$; $I_0 = 2.83$; $F = 0.274$					
		3-ft readings			
1	7.5	6.0	1.5	0.192	7.8
2	6.3	5.3	1.0	0.330	3.0
3	7.5	6.0	1.5	0.192	7.8
4	7.0	5.5	1.5	0.307	4.9
5	7.5	6.0	1.5	0.192	7.8
6	6.5	5.3	1.2	0.330	3.6
7	7.5	6.0	1.5	0.192	7.8
8	7.5	5.5	2.0	0.307	6.5
9	6.0	3.8	2.2	0.60	3.7
Average $I'_\infty = 5.88$; $I_0 = 3.84$; $F = 0.361$ $I'_\infty = 4.44$;* $I_0 = 2.89$;* $F = 0.271$*					

*Omits corner readings.

TABLE 5.20—ESTIMATION OF SOURCE LEVEL ON CONCRETE SLAB AFTER FIRE-HOSING AND SCRUBBING

(Values of I(o), I, I'_A, and I'_∞ are in mr/hr at 1 day)

	I(o)	I	I'_A	q_1	I'_∞
Surface readings					
1	5.1	4.1	1.0	0.257	3.9
2	4.6	2.1	2.5	0.547	4.6
3	4.6	4.1	0.5	0.257	1.9
4	4.8	2.1	2.7	0.544	5.0
5	4.6	4.1	0.5	0.257	1.9
6	4.6	2.1	2.5	0.547	4.6
7	5.6	4.1	1.5	0.257	5.8
8	5.1	2.1	3.0	0.544	5.5
9	4.8	0	4.8	0.92	5.2
Average I'_∞ = 4.27; I_0 = 2.47; F = 0.238					
3-ft readings					
1	7.6	6.0	1.6	0.192	8.3
2	6.4	5.3	1.1	0.330	3.3
3	7.6	6.0	1.6	0.192	8.3
4	7.4	5.5	1.9	0.307	6.2
5	7.4	6.0	1.4	0.192	7.3
6	6.9	5.3	1.6	0.330	4.8
7	7.1	6.0	1.1	0.192	5.7
8	7.1	5.5	1.6	0.307	5.2
9	5.8	3.8	2.0	0.60	3.3
Average I'_∞ = 5.82; I'_0 = 3.80; F = 0.357 I'_∞ = 4.56;* I_0 = 2.98;* F = 0.280*					

*Omits corner readings.

TABLE 5.21—COMPUTATION OF AVERAGE VALUE OF I_0 FOR AREA ABOUT BUILDING B

Area	$\bar{I}_\infty$ (surface), mr/hr at 1 day	$\bar{I}_\infty$ (3-ft level), mr/hr at 1 day	$\bar{I}_0$, mr/hr
Northwest side	32.6	29.3	19.0
Southeast side	43.3	38.0	24.9
Average for area	37.9	33.5	21.9

TABLE 5.22—VALUES OF I_∞ AT MONITOR STATION HEIGHTS ABOVE GROUND LEVEL ON ROOF OF BUILDING B

h, ft	I_∞ (NW), mr/hr at 1 day	I_∞ (SE), mr/hr at 1 day	$\bar{I}_\infty$, mr/hr at 1 day
11.3	24.3	31.9	
14.3	23.2	30.4	
16.5			25.8
19.5			24.8

TABLE 5.23—ESTIMATION OF INITIAL I_A VALUES FOR ROOF OF BUILDING B

	Surface readings				3-ft readings			
	I(o)	p	I*	I_A	I(o)	p	I†	I'_A
1	24.8	0.75	18.2	6.6	23.7	0.80	18.6	5.1
2	21.4	0.50	12.2	9.2	22.6	0.60	13.9	8.7
3	21.4	0.75	18.2	3.2	24.8	0.80	18.6	6.2
4	18.1	0.70	18.0		24.8	0.75	18.6	6.2
5	38.4	0.75	23.9	14.5	28.2	0.80	24.3	3.9
6	37.3	0.50	16.0	21.3	30.5	0.60	18.2	12.3
7	39.5	0.75	23.9	15.6	29.4	0.80	24.3	5.1
8	20.3	0.70	18.0	2.3	16.9	0.75	18.6	
9	28.2	0.40	10.3	17.9	27.1	0.55	13.6	13.5
Sum				90.6				61.0

*$I = p\,I_\infty$; I_∞ = 24.3 for 1, 2, and 3; I_∞ = 31.9 for 5, 6, and 7; and I_∞ = 25.8 for 4, 8, and 9.

†$I = p\,I_\infty$; I_∞ = 23.2 for 1, 2, and 3; I_∞ = 30.4 for 5, 6, and 7; and I_∞ = 24.8 for 4, 8, and 9.

TABLE 5.24—ESTIMATION OF VALUES OF I'_A AND OF F FOR ROOF OF BUILDING B AFTER FIRE-HOSING
(Values of I(o), I, I'_A in mr/hr at 1 day)

	Surface readings				3-ft readings			
Station	I(o)	I	I'_A	F	I(o)	I	I'_A	F
1	15.6	18.2	0	0.00	18.0	18.6	0	0.00
2	20.4	12.2	8.2	0.89	20.4	13.9	6.5	0.75
3	18.0	18.2	0	0.00	21.7	18.6	3.1	0.50
4	16.8	18.0			24.1	18.6	5.5	0.89
5	24.1	23.9	0.2	0.01	20.4	24.3	0	0.00
6	24.1	16.0	8.1	0.38	24.1	18.2	5.9	0.48
7	24.1	23.9	0.2	0.01	22.9	24.3	0	0.00
8	21.6	18.0	3.6	(1.00)	18.0	18.6		
9	16.8	10.3	6.5	0.36	19.2	13.6	5.6	0.41
Sum			26.8	2.65			26.6	3.03
$\overline{F}$				0.296;* 0.331†				0.436;* 0.378†

*From ratio of sums of I'_A and I_A.
†From I'_A/I_A ratios.

TABLE 5.25—ESTIMATION OF VALUES OF I'_A AND OF F FOR ROOF OF BUILDING B AFTER FIRE-HOSING FROM SECOND SET OF READINGS

	Surface readings				3-ft readings			
	I(o)	I	I'_A	F	I(o)	I	I'_A	F
1	21.0	18.2	2.8	0.42	21.0	18.6	2.4	0.47
2	18.7	12.2	6.5	0.71	18.7	13.9	4.8	0.55
3	21.0	18.2	2.8	0.87	21.0	18.6	2.4	0.39
4	21.0	18.0			23.4	18.6	4.8	0.77
5	21.0	23.9	0	0.00	23.4	24.3	0	0.00
6	23.4	16.0	7.4	0.35	23.4	18.2	5.2	0.42
7	25.7	23.9	1.8	0.12	25.7	24.3	1.4	0.27
8	21.0	18.0	3.0	(1.00)	23.4	18.6		
9	18.7	10.3	8.4	0.47	16.4	13.6	2.8	0.21
Sum			32.9	3.94			23.8	3.08
$\overline{F}$				0.363;* 0.492†				0.390;* 0.385†

*From ratio of sums of I'_A and I_A.
†From I'/I_A ratio.

TABLE 5.26—COMPUTATION OF I_∞ AT MONITOR-STATION HEIGHTS ON ROOF OF BUILDING B AFTER SCRAPING AREA

A. Radiation from Field at Decontamination Level (I'_0 = 6.57 mr/hr at 1 day)

Surface readings					3-ft readings				
h, ft	α	I_∞ (NW)	I_∞ (SE)	$\bar{I}_\infty$	h, ft	α	I_∞ (NW)	I_∞ (SE)	$\bar{I}_\infty$
11.3	1.28	8.41	8.41		14.3	1.22	8.02	8.02	
16.5	1.18			7.75	19.5	1.13			7.42

B. Radiation from Outside Decontaminated Circle

Surface readings					3-ft readings				
h, ft	α	I_∞ (NW)	I_∞ (SE)	$\bar{I}_\infty$	h, ft	α	I_∞ (NW)	I_∞ (SE)	$\bar{I}_\infty$
11.3	1.28	15.9	23.5		14.3	1.22	15.2	22.4	
16.5	1.18			18.0	19.5	1.13			17.4
h, ft	p	I_∞ (NW)	I_∞ (SE)	$\bar{I}_\infty$	h, ft	p	I_∞ (NW)	I_∞ (SE)	$\bar{I}_\infty$
11.3	0.342	5.44	8.04		14.3	0.390	5.93	8.74	
16.5	0.420			7.56	19.5	0.456			7.93

C. Total Value of I_∞ at Monitor Stations

Surface readings				3-ft readings			
h, ft	I_∞ (NW)	I_∞ (SE)	$\bar{I}_\infty$	h, ft	I_∞ (NW)	I_∞ (SE)	$\bar{I}_\infty$
11.3	13.8	16.4		14.3	14.0	16.8	
16.5			15.3	19.5			15.4

TABLE 5.27—ESTIMATION OF VALUES OF I'_A AND OF F FOR ROOF OF BUILDING B AFTER FIRE-HOSING AND SCRAPING AREA AROUND THE BUILDING

(Values of I(o), I, and I'_A in mr/hr at 1 day)

	Surface readings					3-ft readings				
	I(o)	p	I	I'_A	F	I(o)	p	I	I'_A	F
1	10.2	0.75	10.4	0	0.00	10.2	0.80	11.2	0	0.00
2	10.2	0.50	6.9	3.3	0.36	10.2	0.60	8.4	1.8	0.21
3	10.2	0.75	10.4	0	0.00	10.2	0.80	11.2	0	0.00
4	12.8	0.70	10.7			12.8	0.75	11.6	1.2	0.19
5	12.8	0.75	12.3	0.5	0.03	12.8	0.80	13.4	0	0.00
6	15.3	0.50	8.2	7.1	0.33	15.3	0.60	10.1	5.2	0.42
7	15.3	0.75	12.3	3.0	0.19	15.3	0.80	13.4	1.9	0.37
8	15.3	0.70	10.7	4.6	(1.00)	15.3	0.75	11.6		
9	12.8	0.40	6.1	6.7	0.37	15.3	0.55	8.5	6.8	0.50
Sum				25.2	2.28				16.9	1.69
$\bar{F}$					0.278;* 0.285†					0.277;* 0.211†

I_∞ = 13.8 for 1, 2, and 3
I_∞ = 16.4 for 5, 6, and 7
I_∞ = 15.3 for 4, 8, and 9

I_∞ = 14.0 for 1, 2, and 3
I_∞ = 16.8 for 5, 6, and 7
I_∞ = 15.4 for 4, 8, and 9

*From ratio of sums of I'_A and I_A.

†From I'_A/I_A ratios.

TABLE 5.28—SHIELDING RESIDUAL NUMBERS FOR MONITOR STATIONS INSIDE BUILDING A RELATIVE TO THE 3-FT INTENSITY (I_∞) FROM GROUND-SURFACE SOURCE LEVEL OUTSIDE

	Before scraping*			After scraping†			After fire-hosing roof		
Station	Surface	3 ft	8 ft	Surface	3 ft	8 ft	Surface	3 ft	8 ft
1		0.04		0.02	0.08	0.18	0.0	0.0	0.0
2		0.14		0.11	0.11	0.18	0.08	0.08	0.15
3		0.19		0.15	0.21	0.21	0.12	0.15	0.35?
4		0.35		0.15	0.15	0.26	0.08	0.08	0.15
5		0.12		0.15	0.08	0.15	0.03	0.04	0.08
6	0.07	0.10	0.22	0.09	0.15	0.21	0.03	0.15	0.15
7		0.39							
8		0.12	0.17						
9		0.18							
10		0.20							
11		0.08							

*I_∞ = 26.9 mr/hr at 1 day.
†I_∞ = 5.70 + 0.92 = 6.62 mr/hr at 1 day.

TABLE 5.29—RESIDUAL NUMBERS FROM MEASUREMENTS INSIDE BUILDING A

Station	At 3-ft after motorgrader scraping	At 3-ft after motorgrader scraping plus fire-hosing roof
1	0.42	0.00
2	0.19	0.14
3	0.27	0.19
4	0.11	0.05
5	0.15	0.09
6	0.37	0.37
Average	0.25	0.14

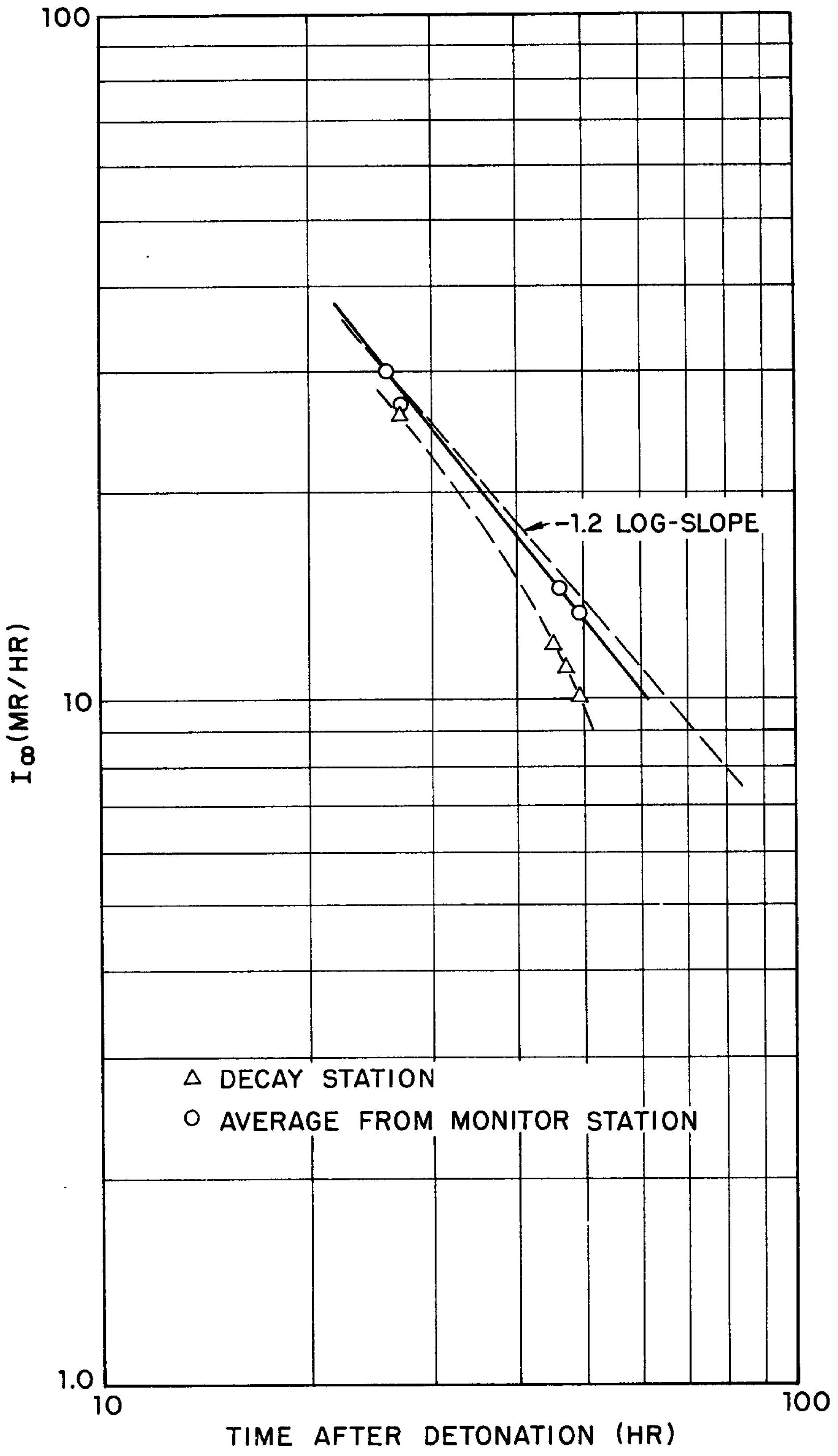

Fig. 5.1—Variation in radiation intensity with time after detonation.

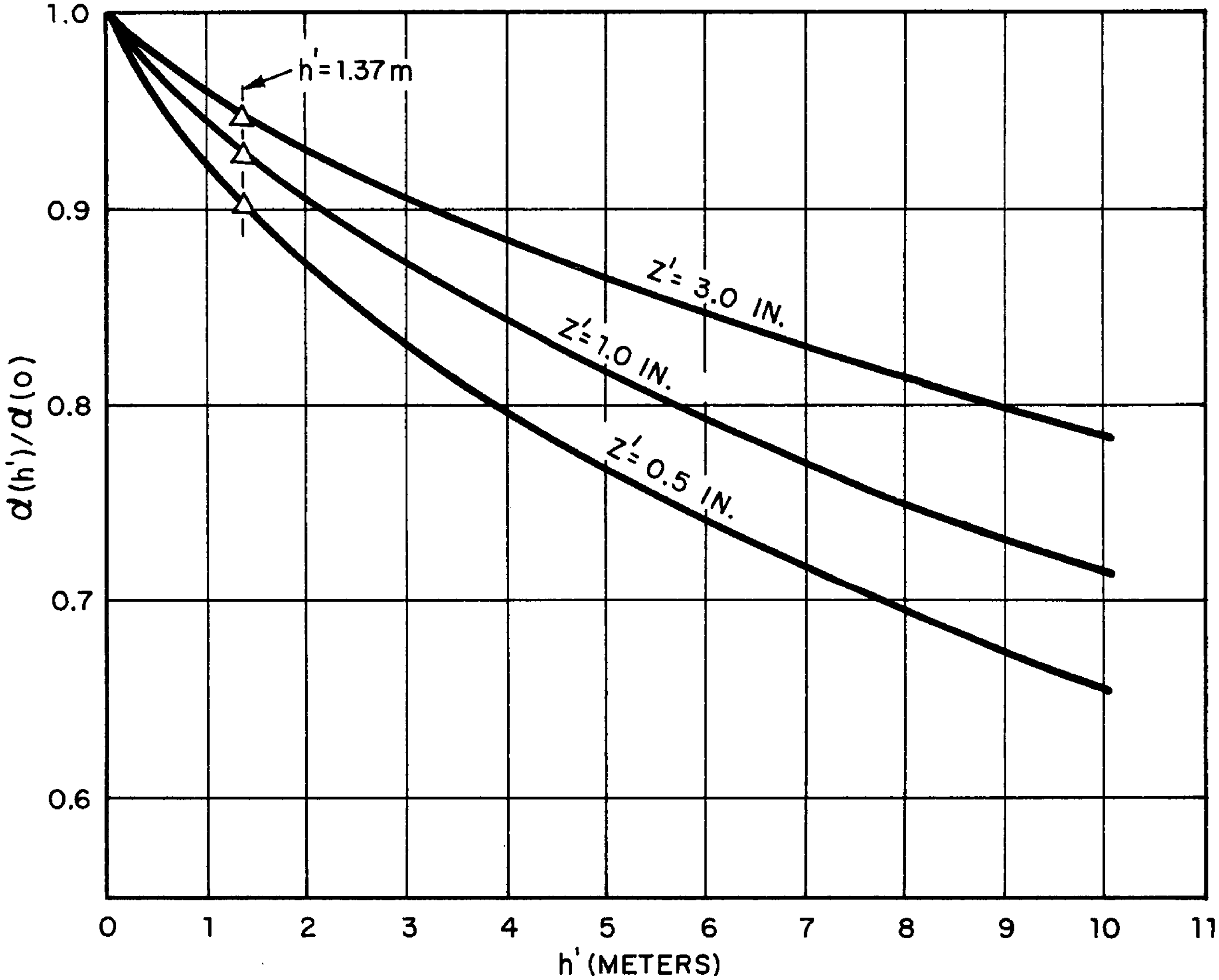

Fig. 5.2—Variation of $\alpha(h^1)/\alpha(o)$ with height.

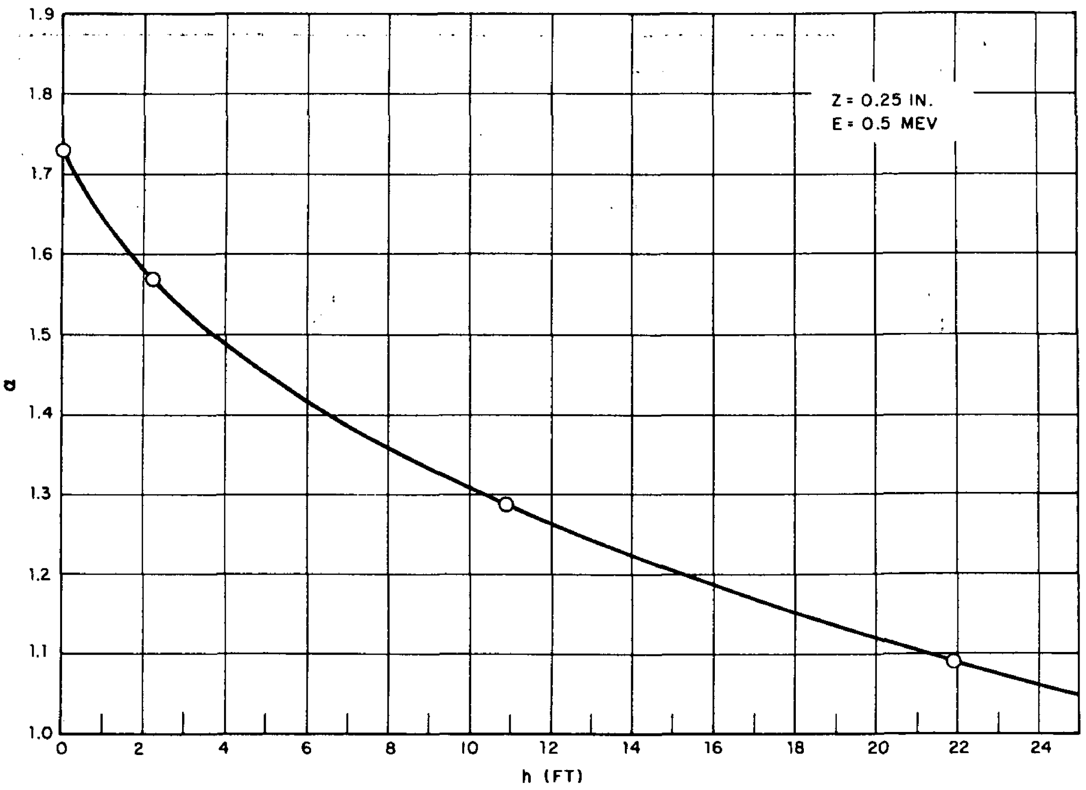

Fig. 5.3—Variation of α with h for experimental data.

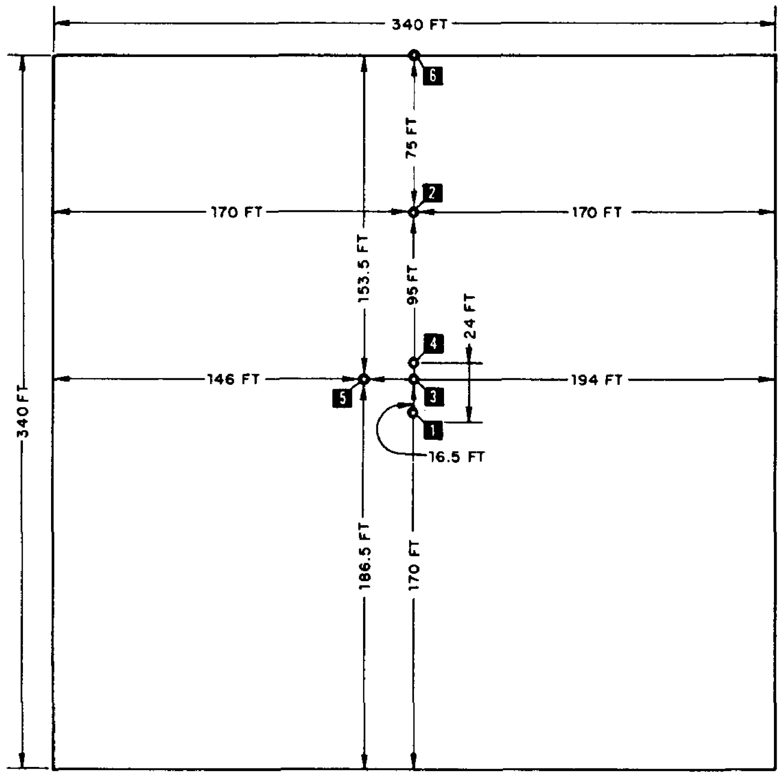

Fig. 5.4—Station layout in area scraped around building A.

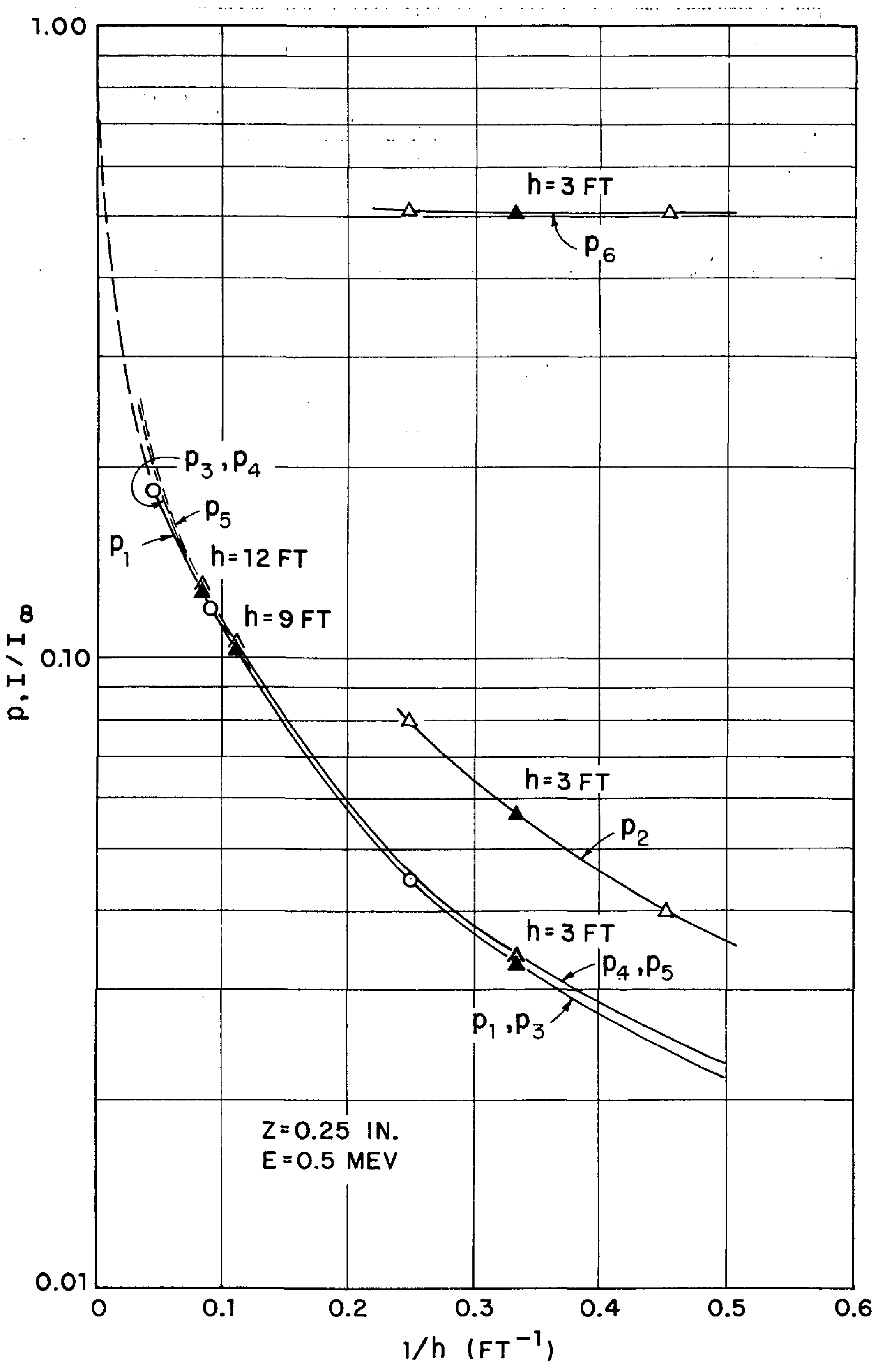

Fig. 5.5—Contribution of sources outside a 340- by 340-ft area at designated stations.

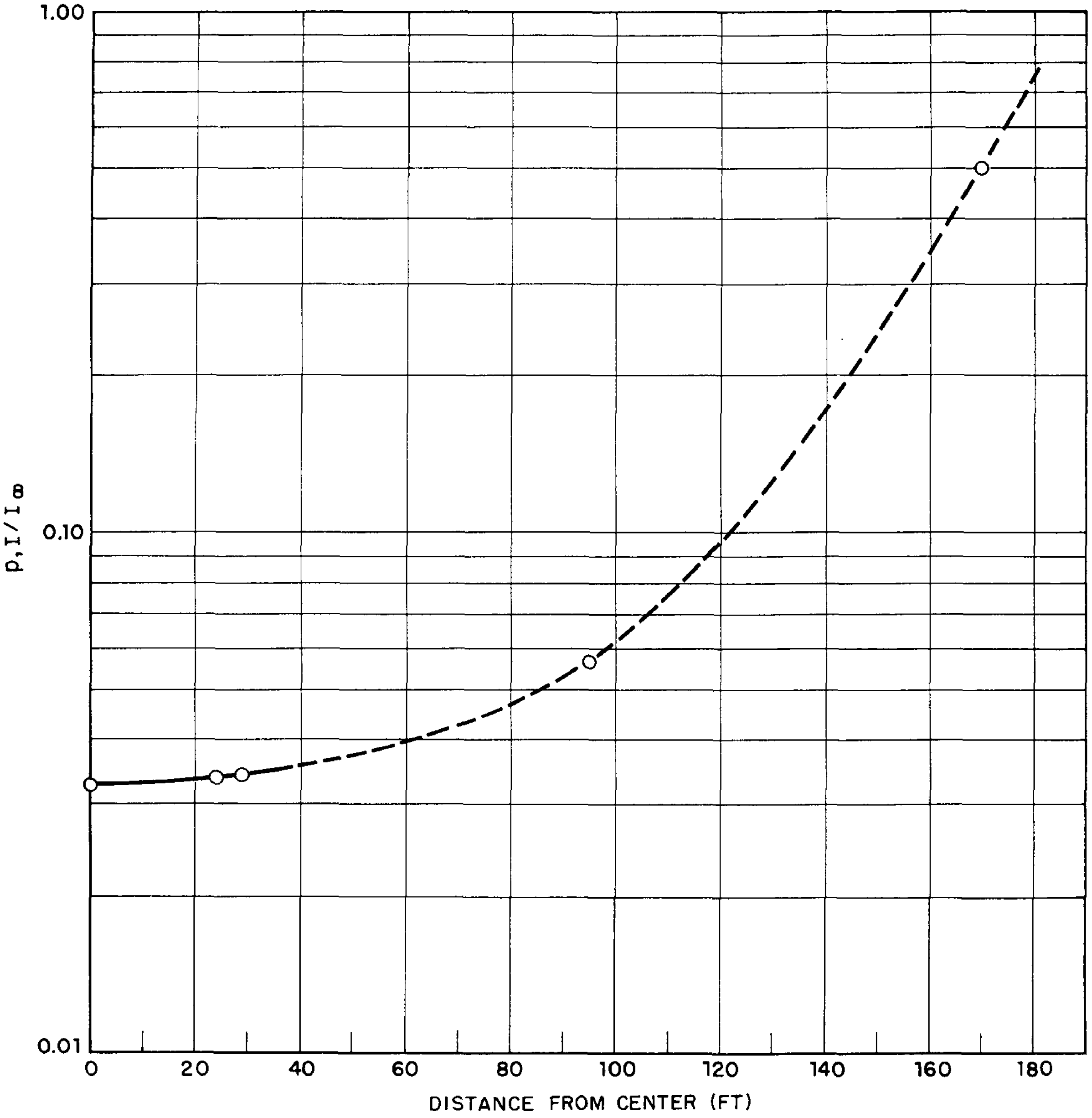

Fig. 5.6 — Plot of I/I_∞ for 3-ft height from center to mid-point of the sides of a 340- by 340-ft square.

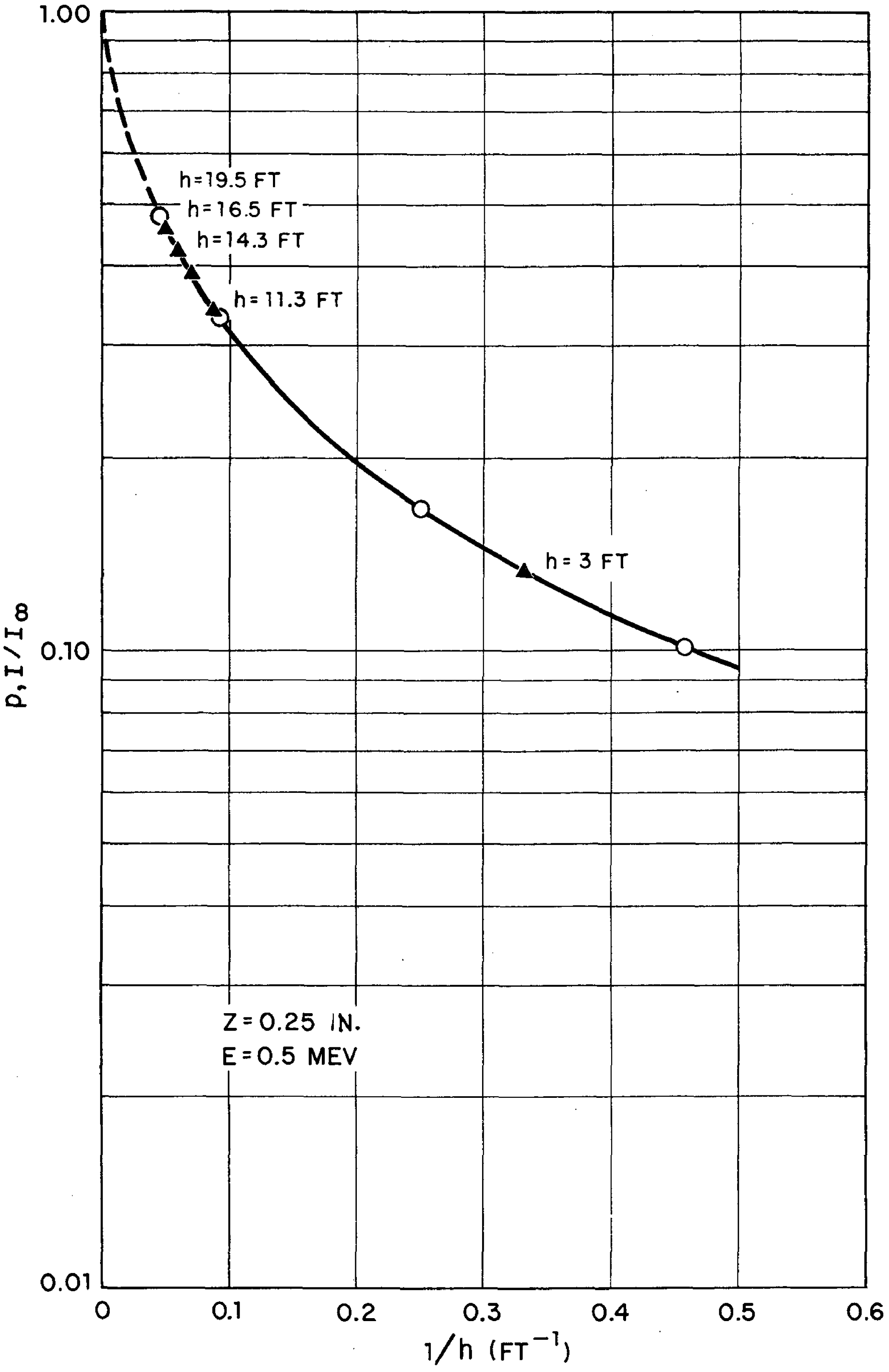

Fig. 5.7—Variation of I/I_∞ with height at center of a circular cleared area of 75-ft radius.

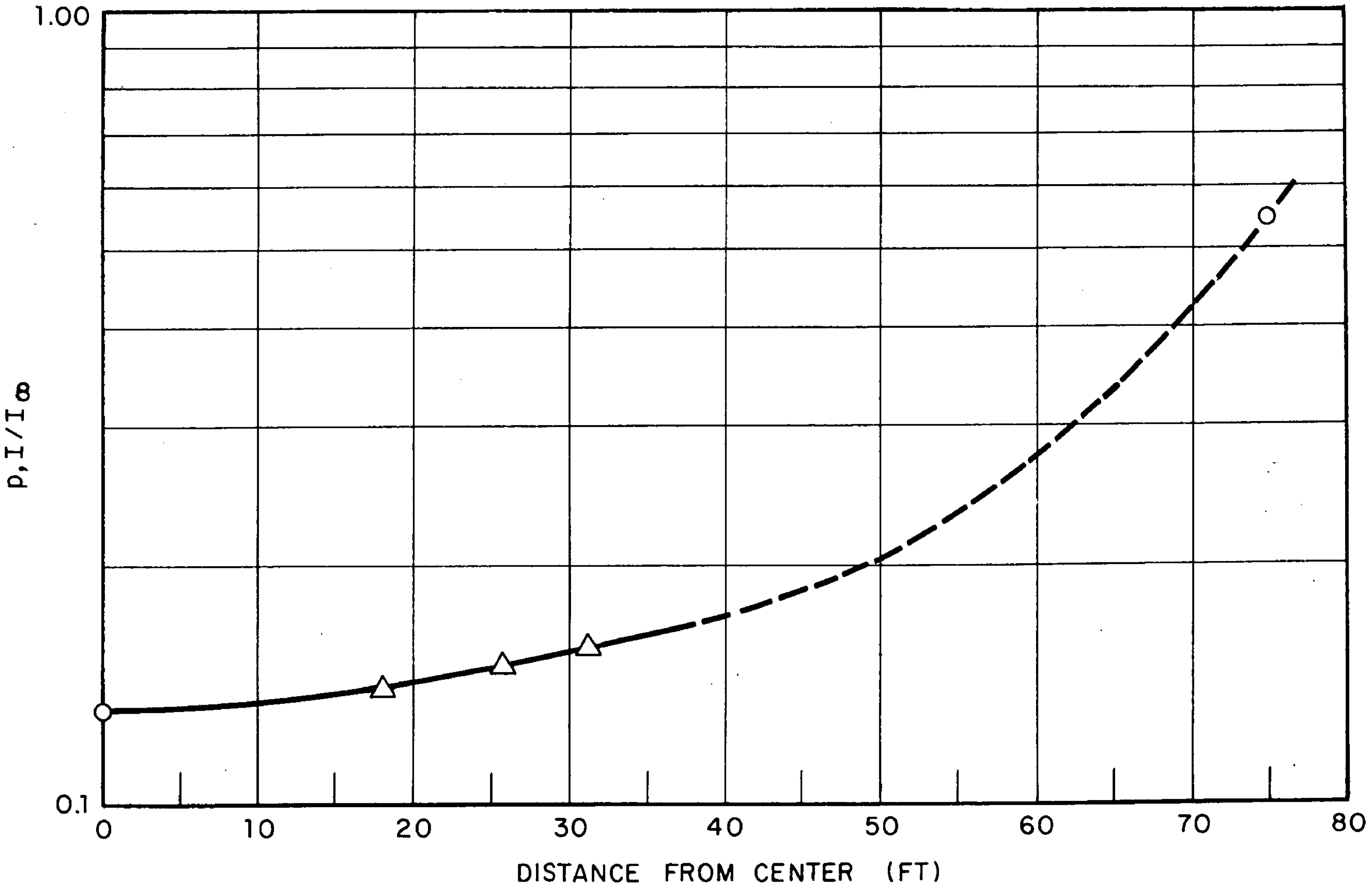

Fig. 5.8—Plot of I/I_∞ at 3-ft height from center to edge of a circle with a 75-ft radius.

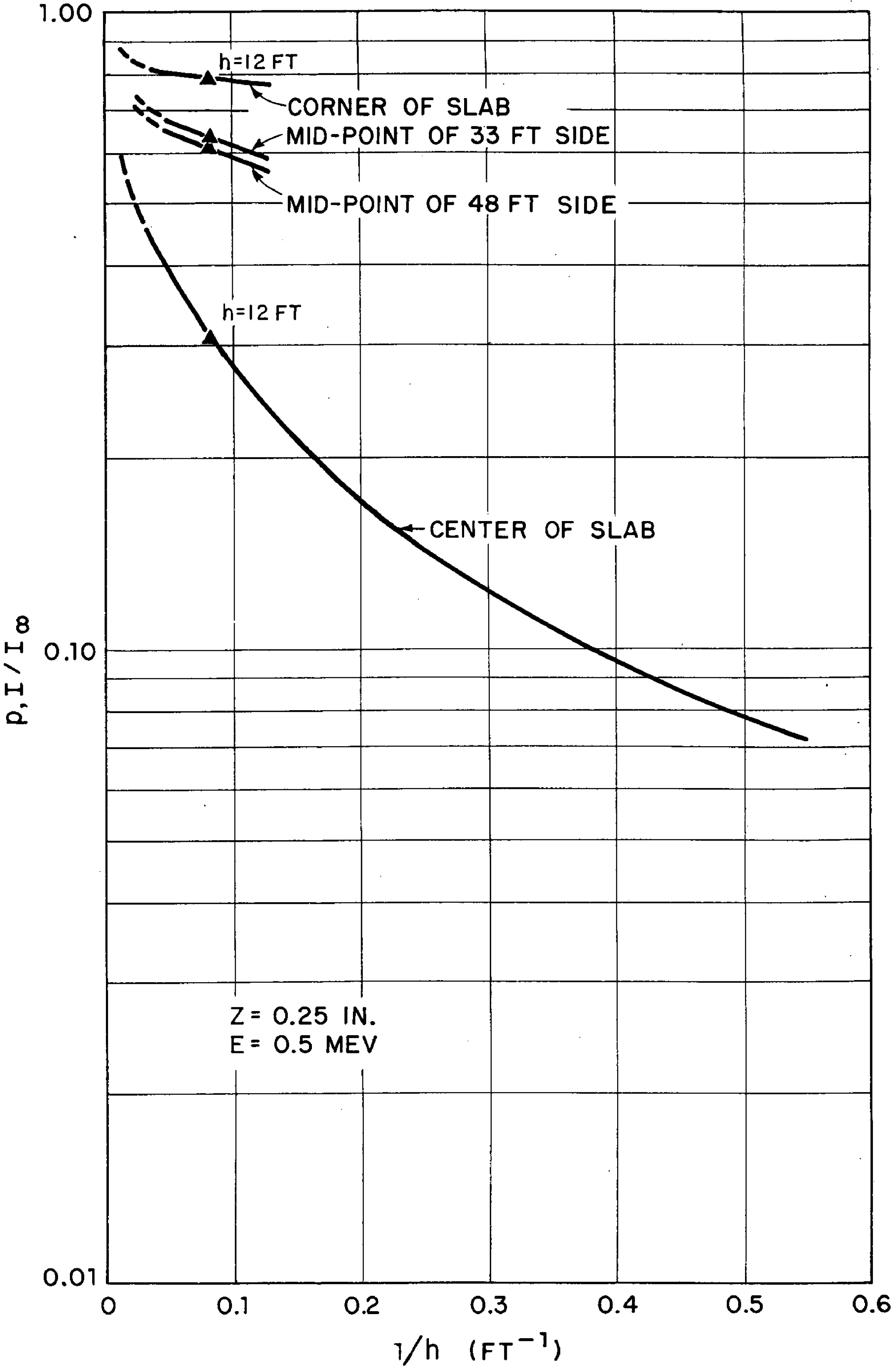

Fig. 5.9—Contributions to radiation from sources outside the shadow cast by concrete-slab roof of building A.

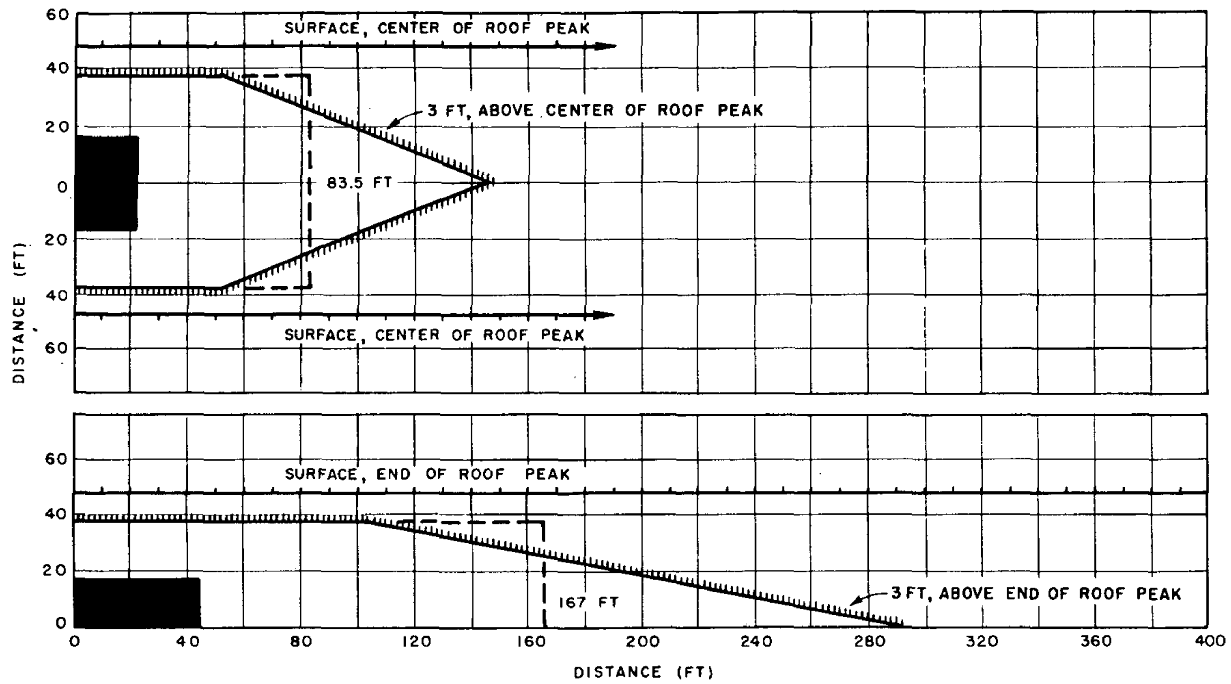

Fig. 5.10—Shielding shadows of building B at roof peak.

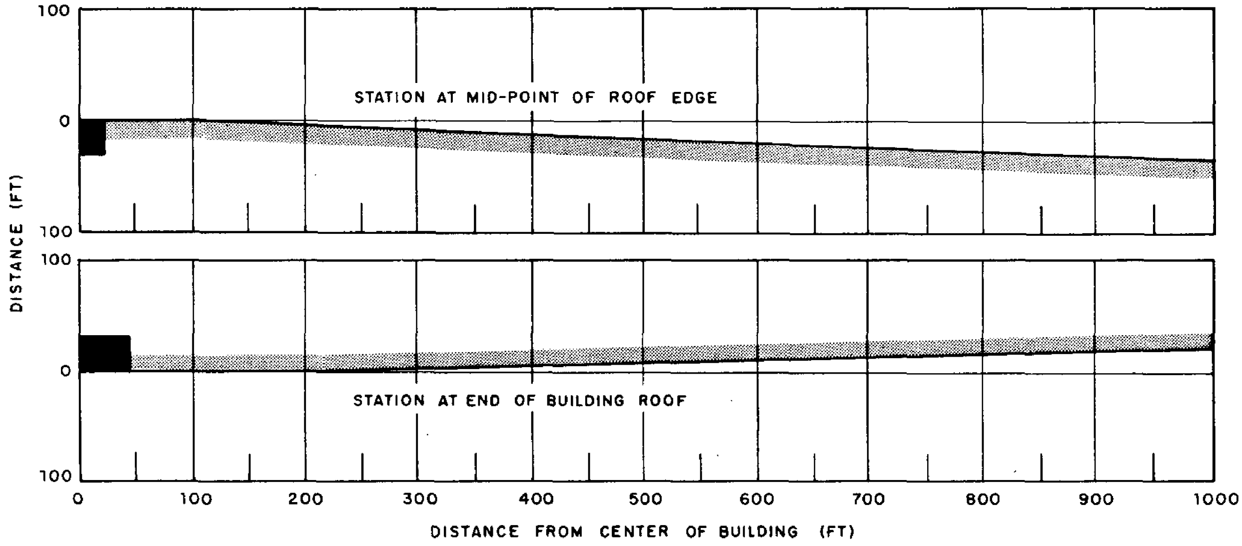

Fig. 5.11—Shielding shadows of building B for 3-ft readings at edge of roof.

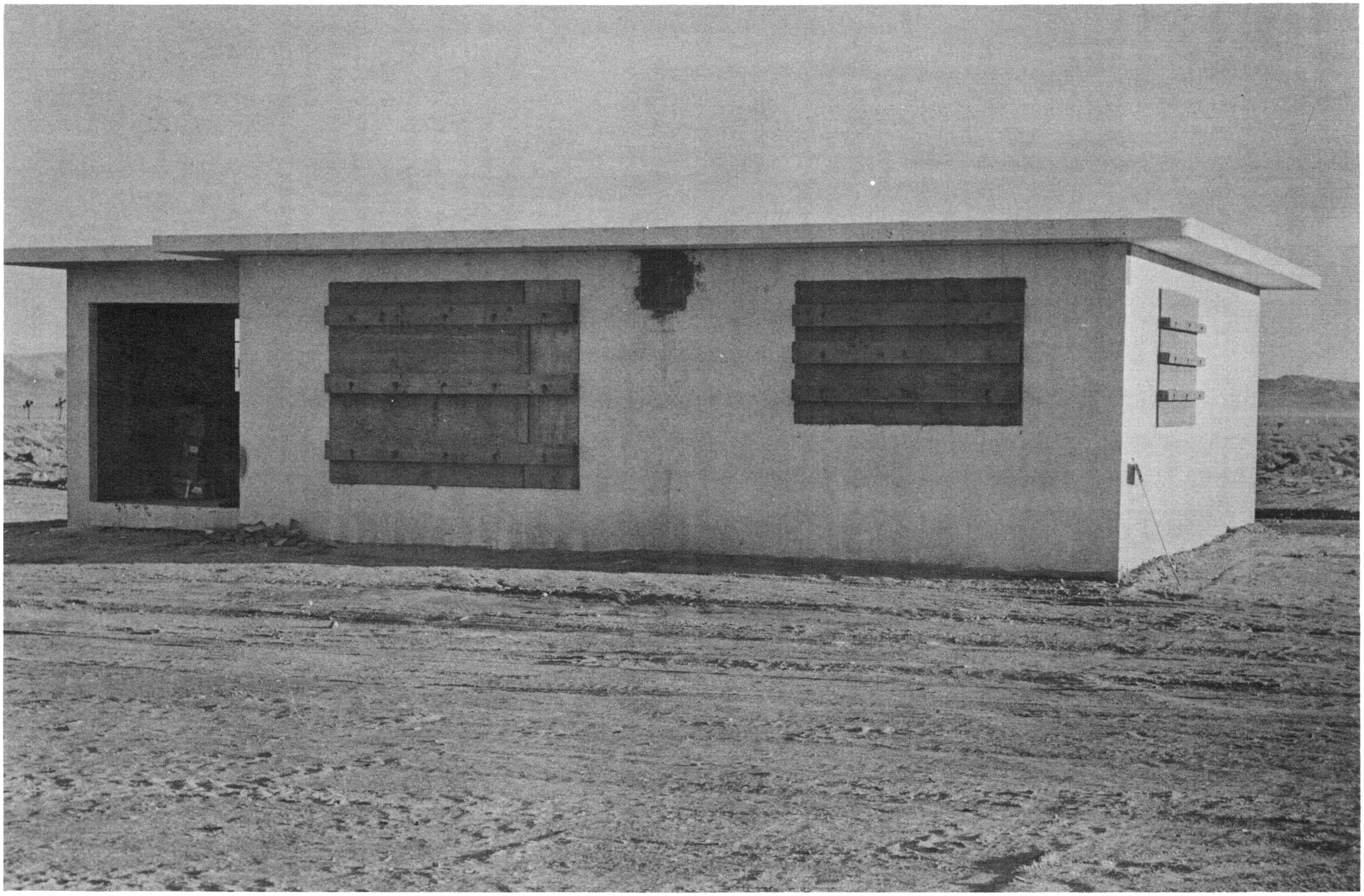

Fig. 5.12—Building A.

Chapter 6

SUMMARY AND CONCLUSIONS

6.1 SUMMARY OF DATA ANALYSIS

The decontamination ratios, as estimated from the experimental data with aid of photon-scattering computations, for the different surfaces and methods are summarized in Table 6.1. No statistical analysis of the results was made; however, a brief survey of the tables giving the computations shows that the errors were not small. It is possible that better, or more reliable, estimates would have resulted if more readings had been taken in locations that were better shielded from outside contributing radiation sources.

In comparison with other results for motorgrading,[1] the values of F given in Table 6.1 are somewhat high; for a 3-in. cut, Ref. 1 gives 0.15 for F. The higher values for F from the present data may be due to the difference in depth of cut as well as the differences in surface roughness of the soil.

The effectiveness values for fire-hosing and scrubbing cannot be directly compared to other data for those methods. For the low initial radiation levels used in these experiments, Eq. 4.4 reduces to

$$F = kR_M \tag{6.1}$$

The presently available values of k and R_M from previous data[1,2] are approximately 2×10^{-4} and 8×10^2 (in an arbitrary system of units), respectively, for fire-hosing concrete; thus the maximum expected value of F for fire-hosing concrete would be 0.16. At the extremely low initial contamination levels used in this experiment, the larger values of F could be due (1) to a much lower particle-size distribution than for the levels at which k and R_M were determined, (2) nonconformance of Eq. 4.4 to the true process at low levels, (3) errors in the photon-scattering estimates, (4) less complete coverage of the surface during this experiment than previously accomplished, and/or (5) other differences in application of the method itself (such as nozzle pressure, rate of application, etc.). There are not enough experimental data available to give a clue as to which of the probable causes of the differences between similar experiments in the field are likely to be important.

For fire-hosing plus scrubbing on concrete the presently available values[1,2] of k and R_M are approximately 2×10^{-4} and 6×10^2, respectively; these give a value of 0.12 for F. This again is lower than the value derived from the present data. For the fire-hosing of composition roofing, the available k and R_M values[1,2] are 1×10^{-4} and 1.4×10^4, respectively. These give 0.14 for the maximum value of F.

Of all the methods used, the motorgrader scraping effectiveness was nearest that obtained in previous experiments. A probable reason for this is that the results achieved by the method do not depend on any interaction between the fallout particles and a surface and hence are not sensitive to the number and size of particles deposited. Excepting for spillage, operator error, and surface roughness, scraping methods that remove an inch or two of the top soil should give a decontamination ratio equal to zero.

6.2 CONCLUSIONS FROM THE DATA

The feasibility of using low-level contamination found, or created, at the Nevada Test Site can best be discussed under two types of experiments: (1) effects of materials and source geometries on the attenuation of gamma rays from fission products and (2) reclamation experiments designed to obtain technical data and to orient and train personnel.

In the first kind of experiment, the chief advantage in using NTS is that a ready-made extended source is deposited when a test is conducted and the height of burst is not too great. In such tests experiments can be conducted to verify scattering computations such as those made in this report. The only requirement is that the magnitude of the intensity of the fields be consistent with the sensitivity of the available radiacs (to be used). Thus measurements to determine shielding numbers in shelters and structures, terrain factors, scattering into cleared areas, and other experiments of this nature could be effectively carried out. The chief disadvantage is the difficulty in obtaining the appropriate radiation levels from a given test device at a given location. Another general disadvantage in using NTS and the fission-product mixture of gamma rays in radiation measurements (especially when a generalized result is desired) is that usually more than 50 per cent of the experimental and data reduction effort is used in determining the experimental conditions themselves before any attempt can be made to interpret the observed effects.

One of the main difficulties in analyzing the data in this report was the small amount of fallout on the test areas. One aspect of this was the low readings on the radiacs; the other, and more important aspect, was the fact that the results obtained cannot be extrapolated with confidence to conditions representing those of either a major or intermediate radiological involvement in a nuclear attack. Countermeasure information at initial levels applicable to these two levels of involvement is where the information is most urgently needed. At NTS such levels could only be obtained from near-surface or shallow underground detonations.

In training personnel, the concept of a radiation field, scattering, decay, and effect of shielding and source geometry on the radiation intensity could be taught and illustrated to advantage at NTS, providing the training is done concurrently with a test series so that the trainees could utilize the more insensitive portable radiacs. Except for surface ground shots, the orientation and training of personnel in decontamination procedures at NTS is not recommended. First, the poor decontamination effectiveness that would be achieved at the low levels could lead the trainee to the conclusion that reclamation is ineffective and not worth the effort; and, second, the realistic high levels and other conditions of contamination representative of those where reclamation really would pay off are not usually available. The actual way a method must be applied, waste-disposal problems, rates of application, and other practical problems of reclamation would all be different at high and low levels of contamination. Since it is relatively simple to prepare synthetic fallout reasonably representative of fallout from land surface bursts,[3] the preferable procedure technically would be to provide a separate facility for the orientation and training of personnel in reclamation techniques as well as for obtaining background technical data.

In summary, the results of Exercise 57-1 lead to the conclusions that (1) experiments involving radiation effects can profitably use the contamination at NTS, providing the levels found are consistent with the sensitivity of the available radiacs (preferably coincident with the weapons tests), and (2) except for detonations near the surface of the ground, experiments involving reclamation procedures and their effectiveness, as well as those involving the orientation and training of personnel in reclamation procedures, cannot profitably use NTS; for these countermeasure operations, low-level contamination (with reference to amount of fallout material, not amount of radiation) should not be used except as an extension of basic research in the field. For applications other than recovery from the radiological consequences of an all-out nuclear war, NTS could be used when the appropriate kind of contamination is produced; the data should be obtained from carefully designed experiments.

The above summary of the results and the summary of the data treatment of Chapter 5 are given as the findings with respect to the original objectives of the Exercise.

TABLE 6.1—SUMMARY OF ESTIMATED EFFECTIVENESS OF RECLAMATION PROCEDURES

A. Effectiveness of Motorgrading Scraping

I_∞ at 3 ft, mr/hr at 1 day	F			Residual number	
	Surface	3-ft	Average	Surface	3 ft
26.9	0.20	0.22	0.21	0.20	0.30
33.5	0.34	0.26	0.30	0.34	0.46

B. Effectiveness of Fire-hosing Concrete Roof

I_∞ at 3 ft, mr/hr at 1 day	F	
	Surface	3-ft
16.1	0.27	0.37

C. Effectiveness of Fire-hosing Plus Scrubbing Concrete Roof

I_∞ at 3 ft, mr/hr at 1 day	F	
	Surface	3-ft
16.1	0.24	0.36

D. Effectiveness of Fire-hosing Composition Shingle Roof

I_∞ at 3 ft,* mr/hr at 1 day	F	
	Surface	3-ft
31.6	0.34	0.35

*$33.5 \times 15/(15^2 + 5.2^2)^{1/2}$

REFERENCES

1. The Radiological Recovery of Fixed Military Installations, TP-PL-13, revised, USNRDL review draft, 1957.
2. C. F. Miller, Estimated Effectiveness of Common Radiological Decontamination Methods for Paved Areas and Building Surfaces, March 1957.
3. C. F. Miller, Theory of Decontamination. Part I, Report USNRDL-460, July 1958.

CIVIL EFFECTS TEST OPERATIONS REPORT SERIES (CEX)

Through its Division of Biology and Medicine and Civil Effects Test Operations Office, the Atomic Energy Commission conducts certain technical tests, exercises, surveys, and research directed primarily toward practical applications of nuclear effects information and toward encouraging better technical, professional, and public understanding and utilization of the vast body of facts useful in the design of countermeasures against weapons effects. The activities carried out in these studies do not require nuclear detonations.

A complete listing of all the studies now underway is impossible in the space available here. However, the following is a list of all reports available from studies that have been completed. All reports listed are available from the Office of Technical Services, Department of Commerce, Washington 25, D. C., at the prices indicated.

CEX-58.1 ($2.75)	Experimental Evaluation of the Radiation Protection Afforded by Residential Structures Against Distributed Sources, J. A. Auxier, J. O. Buchanan, C. Eisenhauer, and H. E. Menker, January 1959.
CEX-58.2 ($0.75)	The Scattering of Thermal Radiation into Open Underground Shelters, T. P. Davis, N. D. Miller, T. S. Ely, J. A. Basso, and H. E. Pearse, October 1959.
CEX-58.7 ($0.50)	AEC Group Shelter, AEC Facilities Division, Holmes & Narver, Inc., June 1960.
CEX-59.1 ($0.60)	An Experimental Evaluation of the Radiation Protection Afforded by a Large Modern Concrete Office Building, J. F. Batter, Jr., A. L. Kaplan, and E. T. Clarke, January 1960.
CEX-59.13 ($0.50)	Experimental Evaluation of the Radiation Protection Afforded by Typical Oak Ridge Homes Against Distributed Sources, T. D. Strickler and J. A. Auxier, April 1960.